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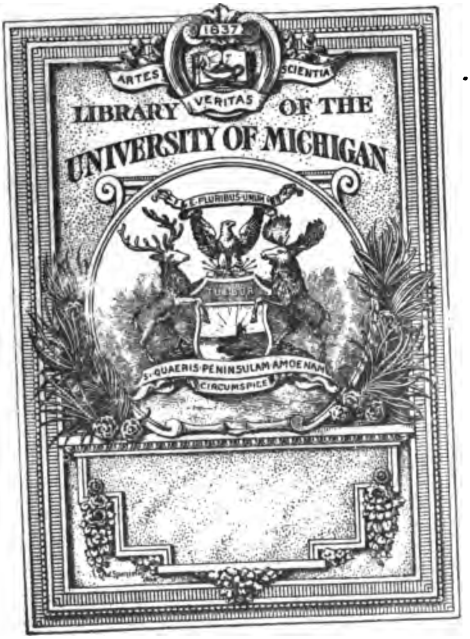
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GAS MANUFACTURE:

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A PRACTICAL HANDBOOK

ON THE PRODUCTION, PURIFICATION, AND TESTING OF
ILLUMINATING GAS, AND THE ASSAY OF THE
BYE-PRODUCTS OF GAS MANUFACTURE.

FOR THE USE OF STUDENTS, CHEMISTS, AND GAS ENGINEERS.

BY

W. J. ATKINSON BUTTERFIELD, M.A., F.C.S.,
HEAD CHEMIST, GAS WORKS, BECKTON, LONDON, E.

With Numerous Illustrations.

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1896.

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PREFACE.

THE enormous growth of the Gas Industry during the past twenty years and the many new departures in the manufacture and application of gas have rendered the older works on Gas Manufacture comparatively useless to the modern student; it was, therefore, with pleasure that I undertook, at the request of the publishers, to endeavour to place at his disposal a text-book embodying the more recent advances.

The raw materials—*e.g.*, coal, coke, oil, &c.—commonly used in the manufacture are dealt with in Chapter I. Following this are two chapters dealing solely with the production of coal gas, which still forms the bulk of the illuminating gas of the world. The modern improvements in apparatus and the most advanced methods of purification are dealt with in these chapters. The recent extensive employment of petroleum for gas-making has almost revolutionized some branches of the industry, and Chapters IV., V., and VI. are chiefly concerned with methods of utilizing mineral oils. The immense importance of a knowledge of the components of gas as a guide to its application, and, also, as an aid at different stages of its manufacture, justifies the introduction of a special chapter on Gas Analysis.

This chapter naturally includes the examination of gas for noxious constituents, which are generally required by statute to be removed from gas before distribution. In this and the succeeding chapter on Photometry the regulations enforced on the Metropolitan Gas Companies are taken as typical, and the methods of testing are based mainly on the requirements of these regulations. Since the gas supplied to London is more nearly free from impurities than that of any other large town in England or on the Continent, and the illuminating power is more rigorously tested there than elsewhere, the directions for testing gas given in this work will not be found to err on the side of laxity. Special attention has been given to those of the proposed standards of light that have partially replaced the historical sperm candle, and may be expected shortly to supersede it in the official testing stations of the Metropolis. The chapter on the Applications of Gas deals not only with gas burners, but also with the employment of gas for heating and motor purposes. In this chapter, the incandescent system of lighting, one of the greatest triumphs of chemical research of the century, is fully dealt with. The chapter on Bye-Products will be of interest, not only to the student of gas manufacture, but also to students of those chemical industries which owe their existence to, and are fed by, the bye-products of gas works.

The illustrations are, for the most part, from original drawings, and everywhere the aim has been to make prominent the essential parts, and, to this end, all unnecessary detail has been omitted. For the illustrations of some patented pieces of apparatus the author is indebted to Messrs. Wm. Sugg & Co., Ltd.; Messrs. Bryan Donkin & Co., Ltd.; West's Gas Improvement Co., Ltd.; and Messrs. Tangye, Ltd.

A knowledge of the elementary facts of chemistry on the part of the reader has been presupposed, and in the portions dealing with analytical methods some acquaintance also with the ordinary operations of quantitative analysis. To any student who has not had such a slight preliminary training, Mr. Hornby's *Gas Engineer's Laboratory Handbook* may serve as a useful introduction to the present work. To him, and other officers at the Beckton Gas Works, I owe more, probably, than I am aware of, for methods of analysis and general information on the subject. To my former tutor, Mr. A. Vernon Harcourt, I am certainly indirectly very much indebted, and I am pleased to have this opportunity of acknowledging my obligation.

W. J. ATKINSON BUTTERFIELD.

BECKTON, *November, 1895.*

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THE CHEMISTRY
OF
GAS MANUFACTURE.

CHAPTER I.

THE RAW MATERIALS OF GAS MANUFACTURE.

The raw materials from which illuminating gas is produced are, from the manufacturing standpoint, best classified according to the methods in use for obtaining the gas from them. Adopting this plan of classification, the raw materials will be ranged under four heads:—

(1) For the production of coal gas.
(2) For the production of water gas.
(3) For the production of oil gas.
(4) For enriching gas of low illuminating power.

By "coal gas" is implied gas produced by the dry distillation of bituminous coal, or other solid carbonaceous matter, in a retort heated externally; by "water gas," that produced by the action of steam on incandescent carbonaceous fuel; by "oil gas," that produced by the distillation of liquid hydrocarbons. The first variety is that which forms the basis of the illuminating gas supplied in England and many parts of Europe; the second variety in combination with the third is extensively employed in the United States of America, and to a limited extent in Great Britain; while the third has special applications in various countries, but in few places forms the staple gas supply. The materials classed under the fourth head are of necessity subsidiary to those under the other heads.

COAL.

The word **coal** has an application sufficiently vague to preclude an exact definition of its meaning, though no one is without a tolerably clear conception of the nature of the substances to which it may legitimately be applied. They are invariably solid bodies whose chief constituent is carbon; hydrogen, nitrogen, oxygen, sulphur, and earthy material being present with it in varying but comparatively small proportions. Coal is the product of the decay of vegetable matter under the protracted influence of heat, pressure, and moisture. Opinions differ as to the amount of influence each of these agencies has exerted on the formation of the final product, but it would appear that they have in general been acting in unison. Bischof decides that the conversion of woody fibre into coal must certainly have been effected by the agency of moisture, and he gives a number of equations expressing the possible chemical changes. The course of the change must, however, be a matter of surmise in our present incomplete knowledge of the agencies that were at work. The bulk of the coal deposits are derived from the remnants of cryptogamic plants, which must have grown, even in northern latitudes, with an abundance and vigour unequalled at the present time in the Tropics. The majority of coal seams are formations of the Carboniferous age, and have become buried by later sedimentary deposits. A few instances of coal of a pre-Carboniferous age are known, and probably graphite is the ultimate product of the more prolonged working of the agencies which produced coal. Coal of more recent formation is found, and as the process of decay of vegetable tissue appears to have been in action in all ages, the less completely carbonized fibre is exemplified in the various kinds of **lignite** or brown coal, and the still more recent **peat.**

Coal of the older deposits contains a very high percentage of carbon, and a very low percentage of hydrogen. The proportion of carbon gradually decreases, and that of hydrogen increases as the more modern deposits are approached. The oxygen varies for the most part in direct ratio with the hydrogen. The inorganic matter varies greatly in amount, and appears to be an intrusion from the alluvial deposits overlying the coal seam when they were in course of deposition. Its nature also varies considerably, according to the nature of the surrounding deposits. A knowledge of the proportions in which carbon, oxygen, hydrogen, and ash exist in a coal is useful for indicating its origin, age, and approximate value as a fuel, but for reasons given later must not be relied on too implicitly. The following table of the percentage composition of various samples of dry wood, coal, and bodies of nature intermediate between them, will indicate the continuity that exists in the series of natural decomposition products of cellular fibre:—

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash.
Cellulose, . .	44·4	6·2	49·4	...	...	...
Dry wood (average)	48·5	6·0	43·5	0·5	...	1·5
„ peat „	58·0	6·3	30·8	0·9	Trace.	4·0
Lignite „	67·0	5·1	19·5	1·1	1·0	6·3
Coal „	77·0	5·0	7·0	1·5	1·5	8·0
Anthracite „	90·0	2·5	2·5	0·5	0·5	4·0

Cellulose.—Impure cellulose is readily obtained from many fibrous substances, and is met with in commerce as jute. Purified cellulose is known as "cotton wool;" when washed free from fatty matters it is designated "medicated." It is of interest to gas chemists as being a pure carbohydrate on which the progress of the process of carbonization can be watched; the action and products being uninfluenced by the presence of several complicated carbon compounds. This matter is of interest in elucidating the process of carbonization. The composition of wood varies according to the nature of the tree and the time of year at which it was cut. On exposure to air it loses a large amount of moisture; the percentage in freshly cut wood varying, according to its nature, from 30 to 50, and diminishing by nearly 20 per cent. on long-continued exposure to the air in a dry place. The chief constituent of wood is cellulose, and dry wood behaves very similarly to cellulose on dry distillation, but the products are more numerous and the reactions less defined, being complicated by the other constituents of woody fibre. The ultimate composition of a few varieties of wood, dried at 100° C., is indicated in the following table:—

	Specific gravity.	Carbon.	Hydrogen.	Oxygen (including Nitrogen).	Ash.
Oak, .	0·75	49·3	6·1	43·0	1·6
Beech, .	0·58	48·0	6·1	44·8	1·1
Pine, .	0·42	49·1	6·3	43·6	1·0

On destructive distillation, wood gives up its water first, and then yields empyreumatic oils, pyroligneous or impure acetic acid, wood spirit, acetone, and a quantity of gas, while charcoal remains in the retort. The gas varies considerably in composition, according to the nature of the wood, the amount of water it contains, and the temperature of distillation, but it invariably contains a large percentage of carbonic acid. Wood gas is used for illuminating purposes only under exceptional conditions, but its manufacture and composition are interesting to the gas engineer for the complete comprehension of the phenomena of the destructive distillation of carbonaceous material.

Peat.—The first formed natural decomposition product of cellular fibre is known as peat, and is found in large quantities in the bogs of Ireland, the moors of Scotland and England, and in many parts of the Continent. In its natural state peat contains a varying but always large proportion of water, which is partly given up on exposure to the air in a dry place, but completely only when heated. Freshly dug peat frequently contains 80 or even 90 per cent. of water; when dried under cover by long continued exposure to the air, 12 to 30 per cent. of its weight is water, and this amount does not diminish on further exposure. Peat thus air-dried on heating at 100° C. loses from 10 to 30 per cent. of its weight, by the loss of water chiefly, but also of small quantities of volatile hydrocarbons. The amount of ash contained in peat varies, of course, greatly according to its origin, but in the best varieties does not exceed 1·5 per cent. on the air-dried sample. 4 per cent. of ash is an average amount, and many peats in use contain nearly 10 per cent., but more than that is sufficient to condemn them for ordinary purposes. The specific gravity of peat is very variable, according to the amount of water and ash present, but also according to the state of aggregation, ranging from 0·3 to 1·20 in the dry state. The former specific gravity is only found in particularly fibrous specimens, the latter only in dense compact peat almost destitute of fibre. The quantity of water naturally contained in peat, and the difficulty and expense of its complete removal render peat valueless as a fuel where coal is reasonably cheap, and for the same reason it is seldom used for gas making. But in districts where coal is scarce peat is used with some measure of success for gas manufacture. For this purpose it is generally compressed and moulded into bricks of regular size, the moisture being as far as possible removed. Elaborate systems of drying chambers and shaping machines have been devised and are in use in towns bordering on the peat moors of Austria. The amount of water remaining in the peat after treatment seldom exceeds 10 per cent., and the specific gravity of the briquettes sometimes reaches 1·1. The composition of dried peat is fairly constant when the ash is eliminated from the analytical results. Good Irish peat will be found to have approximately the following composition, water and ash being disregarded:—

Carbon,	61·0	per cent.
Hydrogen,	6·5	„
Nitrogen,	1·0	„
Oxygen,	31·5	„

Its constitution indicates that peat is formed from woody fibre by the elimination of hydrogen and oxygen as water, of carbon and oxygen as carbonic acid, and in less amount of carbon and hydrogen as marsh gas, the net result of these changes being a considerable increase in the proportion of carbon, and decrease in the proportion of oxygen. Were the process continued still further, a substance having the composition of lignite or brown coal might be expected to result. Peat being therefore virtually a body intermediate in nature between wood and coal, it might be expected to yield on destructive distillation, products intermediate in character and quantity, between those obtained from those two substances. Such is in reality the case, though the true relation of the products of destructive distillation of wood, peat, and coal to one another is frequently obscured by the quantity of moisture in the peat. This tends to lower the temperature of carbonization, and consequently the result is not comparable strictly with the result of the carbonization of coal as ordinarily carried out. Perfectly dry compressed peat yields at a red heat 11,000 cubic feet of gas per ton; after purification by lime the gas has an illuminating power of 17 to 18 candles. The coke retains the form of the peat, and amounts to nearly 9 cwts. per ton carbonized, while 15 gallons of tar are obtained, as well as a quantity of ammoniacal liquor. The crude gas from peat contains more carbonic acid than that from coal, and the amount increases with the water present in the peat, but the gas is less contaminated with sulphur compounds. The expense of drying the peat and of purification of the gas leave it out of question as a material for gas manufacture where coal is at all accessible, but the absence of the latter mineral in some parts of Europe has directed attention to peat for gas making.

Lignite or **brown coal** is vegetable matter in a more advanced stage of decay than peat, and approaches more nearly the true coals in composition. In many lignites the forms of trees and plants are clearly visible, and indicate the nature of the vegetation that existed at the time the beds were formed. This consisted mainly of mosses, algæ, and other cryptogamic plants, growing with a profusion no longer observed in the same latitudes. True lignite contains very little bituminous matter, but some of the brown coals are nearly as rich as ordinary bituminous coal, and, indeed, the two varieties merge almost imperceptibly into one another. Lignite is found in small quantities only in England and France, but large deposits occur in Germany and Austria, especially in Silesia, Saxony, and Bohemia. Its average composition is—Carbon, 69 per cent.; oxygen (and nitrogen), 20 per cent.; hydrogen, 5 per cent.; ash, 6 per cent. The lignite from the neighbourhood of Dartmoor has a specific gravity of 1·13, and gives on analysis :—

Carbon, ...	66·3 per cent.
Oxygen (and nitrogen), ...	23·4 ,,
Hydrogen, ...	5·6 ,,
Sulphur, ...	2·4 ,,
Ash, ...	2·3 ,,

In the natural state lignite generally contains a large amount of water, sometimes amounting to 20 per cent. of its weight, and requires drying by exposure under cover to the air before it can be used profitably for gas making. The experience of English gas managers shows, however, that though a large yield of gas, in some instances 13,000 cubic feet per ton, may be obtained from lignite, the quality of the product is very poor, its illuminating power often being only 8 candles, and the coke is of little value. The tar, too, though valuable in itself, when mixed with ordinary coal tar causes difficulties in the working up of the latter which detract greatly from its value. The tar and ammoniacal liquor from lignite have a most objectionable odour, resembling, but more intense than, that of a decoction of cabbages. The brown coals of Germany and Austria are, however, somewhat extensively used in those countries for gas manufacture. They vary in colour from a dirty yellow to a dark brown, and are often found in proximity to and overlying strata of black coal. The specific gravity ranges from 1·15 to 1·35, and the yield of coke, which is of fair quality, from 25 to 45 per cent. of the coal carbonized. Some of these coals are rich in bituminous matter, and give on distillation at a low temperature, burning and lubricating oils of marketable quality. The yield of gas does not, however, as a rule, exceed 9,000 cubic feet per ton, and often is only 7,000 cubic feet, while its quality is inferior to that of gas from ordinary black coal. The brown coals of Germany contain from 20 to 40 per cent. of water, which is only partially removed on exposure to the air in a dry place, but this air-drying is generally considered sufficient to render them fit for carbonizing. The fibrous samples contain more oxygen than the close kinds, but the average composition of the organic matter of the dry coals may be taken as—Carbon, 70; oxygen, 25; hydrogen, 5. The value and constituents of tar from lignite will be dealt with briefly in Chapter x.

Coal.—The products of the partial natural decay of cellular fibre having been for the most part considered, we come to what may be regarded as the ultimate product of the natural decomposition of vegetable matter buried beneath the earth's surface, namely coal. Reserving the richly bituminous cannels to the end of this section, and anthracite and anthracitic coals (which are valueless for retorting) to the next section, there are still several varieties of coal to be considered. Many classifications of coal according to its properties have been proposed, but as there are no marked lines of demarcation, and coals intermediate between the classes adopted are known, it is evident that such divisions must be purely arbitrary and have no natural basis. A broad classification is, however, useful to indicate the value of particular coals for special purposes, and with this end in view they will be considered under the two heads of Caking and Non-caking Coals.

Caking coals are distinguished by softening or fusing on heating, and yielding on the expulsion of volatile matter by heat a carbonaceous mass of cellular structure presenting no evidence of the form or shape of the original coal. The production of this mass of coke does not appear to be dependent on the ultimate composition of the coal, but rather on the forms of combination of the elements existing in it, which are in turn determined by the conditions of formation and geological position. Hence we find coals of one district cake on heating, while coals of almost precisely similar elementary composition from another district do not cake. Caking coal usually is pure black, and fairly lustrous, having a specific gravity from 1·25 to 1·35. The organic matter of the coal contains from 80 to 90 per cent. carbon, 4·5 to 6·0 per cent. hydrogen, 5 to 13 per cent. oxygen, and 1·0 to 2·5 per cent. nitrogen. Caking coals give on dry distillation from 60 to 80 per cent. of coke, the average from good Durham gas coals being about 68 per cent. The amount of ash is, of course, very variable; it may be 2 per cent. or even lower, or reach 12 per cent. The average of tests on fourteen representative samples of good Durham gas coal examined by me is 7·5 per cent. of ash. An obnoxious constituent of most caking coals is sulphur, which exists in them partially in combination with iron as pyrites, and partially organically combined. The bulk of the gas manufactured in this country is required to contain less than a certain small proportion of sulphur, consequently it is to the interest of the gas engineer to use coal which yields only a small amount of sulphur to the gas in order to save the expense of its removal from the latter. A certain proportion, varying with the kind of coal, of sulphur remains in the coke, and this must be deducted from the total sulphur in the coal to give the amount that is delivered up to the gas on carbonization, and this so-called "volatile" sulphur is the criterion on which the purity of a coal is judged by gas chemists. The form in which the sulphur is combined in the gas is of considerable but secondary importance. The sulphur in gas coals is rarely under 0·5 per cent., but should never exceed 2·5 per cent. The extent to which sulphur is harmful will be considered at length when the methods of estimating its amount in coal and coke are given. Phosphorus is sometimes present in coal, but the greater part remains in the coke. In the natural state caking coals contain from 1 to 10 per cent. of water.

Non-caking coals, when heated until all volatile matter is expelled, yield a coke which retains the form of the coal, or crumbles into small fragments. No fusion or softening of the coal is apparent, and the coke has not a deeply seamed surface or open cellular structure. The coal frequently has a slight brown tint; its specific gravity varies from 1·25 to 1·40. The ultimate composition of the organic matter of the dry coal is:—Carbon, 70 to 85 per cent.; oxygen, 10 to 18 per cent. (occasionally considerably less); hydrogen, 4·25 to 6·0 per cent.; nitrogen, 1 to 2 per cent.; and sulphur, 0·5 to 1·5 per cent. It is evident that non-caking coals do not differ markedly from caking coals in their elementary composition, and the classification must depend primarily on the behaviour on heating. The yield of coke from non-caking coals is generally less than from caking coals; they contain, as a rule, more water, and about the same proportion of ash.

Caking coals are found in the following localities in Great Britain:—Northumberland, Durham, Yorkshire, Nottingham, parts of South Wales, North Wales, and Cumberland, and in smaller quantities in other parts.

Non-caking coals are found in the following localities:—Staffordshire, Derbyshire, Lancashire, parts of Yorkshire, South Wales, and Scotland, and in smaller quantities in other parts of Great Britain.

Cannel coal appears from its elementary composition to hold a position intermediate between the lignites and the bituminous black coals, but the conditions under which it was formed have caused different hydrocarbons to enter into its constitution, and it differs considerably from either of those varieties. Water appears to have been a more important agency in the formation of cannel than in the formation of coal from vegetable matter, and probably was the chief factor in determining the nature of the product. The organic matter of cannel generally has a composition falling between the following limits for each constituent: —Carbon, 70 to 85 per cent.; oxygen, 5 to 15 per cent.; hydrogen, 5·5 to 10 per cent.; nitrogen, 1 to 2·5 per cent.; sulphur, 0·5 to 2·5 per cent. Cannels vary in specific gravity from 1·1 to 1·4. They are usually of a dull black colour, sometimes inclining to brown, and split up in a manner resembling slate, the fracture being more or less conchoidal. On heating they decrepitate and burn with a white but strongly smoking flame. The percentage of ash in most of the cannels now obtainable is much higher than in good bituminous gas coals; in the best kinds it was often as low as 2·0, but is now usually from 5·0 to 20·0. The ash is generally more white and free from iron than that of ordinary coal. In general the coke obtained is in the form of the cannel, or quite powdery, and is from its nature as well as its large content of ash comparatively valueless as a fuel. The yield of coke is from 30 to 70 per cent. of the weight of cannel carbonized, being largely dependent on the amount of ash in the cannel. Cannel coal is very widely distributed over the globe, but is not found in extensive deposits. Seams frequently crop up among deposits of common coal. Traces of its vegetable origin are very commonly visible in the impressions of leaves and plants remaining in the cannel. Some varieties, such as the well-known Boghead, are rather more correctly classed as bituminous shale than as coal; extensive deposits of a mineral of this nature are found in Australia. The evaluation and testing of cannel are carried out in a similar manner to the assay of ordinary coal for gas making, and will be considered with that.

The Analysis of Coal.—It is often desirable for the gas manufacturer to ascertain the elementary composition of a sample of coal. The method of conducting combustions will have been learnt in the course of the students' ordinary laboratory training, and need not be here described. The following suggestions are applicable to the particular case of the analysis of coal, and may be of assistance to one who has not a special acquaintance with the testing of that mineral. In the estimation of carbon and hydrogen, lead chromate should be used in place of the copper oxide usually recommended for combustions of organic substances, and the forward portion of the tube containing it should be less strongly heated than is customary. Sulphur will not then be estimated with the carbon. Six inches of the fore part of the tube should be packed with finely divided silver, silver gauze, or lumps of pumice on which silver has been deposited, and this portion should be heated to bright redness. Some of the modern gas furnaces are much superior to the old type of Erlenmeyer for combustion work, and should be used if possible. Sulphuric acid pumice tubes will be found more reliable than tubes filled with calcium chloride for the collection of the water formed by the combustion. If calcium chloride is used, it must not contain free alkali, as is usually the case with commercial samples. Liebig or Geissler potash bulbs are generally preferred to soda-lime tubes for the collection of the carbonic acid; if soda-lime is used it should be freshly prepared and a large tube, or preferably two tubes weighed separately, employed. Wherever U-tubes are required those with hollow glass stoppers ground in should be used instead of the old pattern with caoutchouc plugs; with the stoppers closed to the inlet and outlet tubes they remain constant in weight for any length of time.

Nitrogen in coal may be estimated either by Dumas' method of directly measuring its volume, or by Kjeldahl's process. The latter is also a very good method for determining the nitrogen in coke. The sulphuric acid used must be free from oxides of nitrogen.

Sulphur and **phosphorus** may be estimated by Carius' method, which consists in digesting the finely-powdered coal with strong nitric acid for three hours in a sealed tube at 200° C. The contents of the tube are diluted with water, and the sulphur estimated as barium sulphate by precipitation with barium nitrate in the usual manner. The filtrate is neutralized with ammonia, and ammonium chloride and magnesium chloride are added to precipitate the phosphorus, for ignition and weighing as magnesium pyrophosphate. The amount of phosphorus is not usually determined in an analysis of coal; the amount generally present may be seen from the following results by Ad. Carnot.* In Newcastle and Boghead coal traces only were found; in Lancashire coal, 0·02852 per cent.; in Wigan coal, 0·02246 per cent.; in Glasgow coal, 0·00572 per cent.; in Commentry coal, 0·00163 per cent.; and in Commentry cannel, 0·04260 per cent. This investigator observed that phosphorus was present in the greatest quantity in the visible spores of cannel. To determine phosphorus in coal and coke, F. L. Crobaugh ignites the powdered mineral, and fuses the ash with sodium carbonate containing 10 per cent. of potassium nitrate. The mass is taken up in warm dilute nitric acid, the liquid filtered, and ammonium molybdate added to the warm filtrate. The precipitate is thoroughly washed, dissolved in ammonia, barely neutralized with hydrochloric acid, and the phosphoric acid estimated by precipitation with mangnesium chloride, and weighing as magnesium pyrophosphate. For full details, his paper in the *Journ. Anal. and Appl. Chem.*, vol. vii., p. 223, should be consulted.

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* *Comptes Rendus*, xcix., 151.

Sulphur in coal is most accurately and certainly determined by Nakamura's method. A small, but representative, sample of the coal is ground in an agate mortar until the whole of it will pass through very fine muslin. From 1 to 2 grams of the powdered coal is weighed out accurately, and carefully mixed with about four times its weight of mixed dried alkaline carbonates (in the proportions of 13 parts anhydrous potassium carbonate to 10 parts anhydrous sodium carbonate) in a large platinum crucible. The crucible is partially covered and very slightly warmed over a spirit lamp. No odour or smoke should issue from the crucible. The heat is very gradually increased for two hours, at the end of which time the crucible may be just visibly red, and the contents should have gradually faded to a pale gray colour. If smoke or smell has been detected from the crucible at any time, a loss of sulphur will have probably occurred. The heat is increased to redness for an hour, and the white mass remaining in the crucible is extracted with water. The extract is passed through a filter paper, a little bromine water added, and the liquid boiled to expel the excess of bromine. It is then acidified with hydrochloric acid, and the sulphur precipitated in the usual way as barium sulphate. From the weight of barium sulphate obtained that of the sulphur is found by the usual calculation (the weight of barium sulphate multiplied by $\frac{32}{233}$, or 0·1373, gives the weight of sulphur contained in it). From the weight of coal taken and the sulphur found, the percentage of sulphur in the coal is ascertained. This method of estimating sulphur in coal is perfectly reliable, but requires manipulative skill and patience on the part of the operator. An error is introduced if gas is used for heating the crucible instead of spirit, but it is not large if the gas complies with the requirements of the sulphur clauses of the Metropolitan Gas Referees, and may be disregarded, or blank experiments may be carried out, and a deduction made accordingly. The results obtained by Nakamura's method will be trustworthy, only if the coal is in very fine powder, and if the heat is applied and increased so moderately that no odour of hydrocarbon vapour can be detected in the products escaping from the crucible. The process depends on the slow, but perfect, oxidation of the whole of the organic matter of the coal, and smoke or odorous vapours imply imperfect oxidation.

A method for the estimation of sulphur in coal depending on a totally different principle has been proposed by F. Stolba.* According to his instructions about 1 gram of the finely-powdered coal, accurately weighed, is mixed with 1 gram of finely-powdered silver, and 1 gram pure dry potassium bicarbonate, and heated in a crucible with constant stirring for about twenty-five minutes, or until all dark particles have disappeared. A little ammonium nitrate is added to the residue when cool, and it is again warmed, and on cooling extracted with dilute hydrochloric acid. The solid particles are removed by filtering, and the sulphur in the filtrate and washings determined in the usual way as barium sulphate. The results are accurate, and the method is more rapid than Nakamura's. Many methods, based on heating the coal with a deflagrating mixture, have been proposed for estimating sulphur in coal, but though less tedious than Nakamura's, they are not so reliable, and cannot be commended for use in a gas works laboratory.

The incombustible matter or **ash** in coal is found by burning off completely all combustible matter in a fair sample. The determination of the ash in coal and coke is so frequently required that it may be described here, at the risk of encroaching on the ground covered by more general text books. A fair sample of the coal or coke is roughly powdered, and a platinum boat (previously cleaned, ignited, and left to cool in a desiccator) is carefully weighed. Sufficient of the powdered coal to cover the bottom of the boat about one-eighth inch deep is put into it, and it is again weighed. The difference between the first and second weighings gives the weight of coal taken. A tube of porcelain or hard combustion glass, of sufficient diameter internally to readily admit the boat and about 2 feet long, is connected at one end to an aspirator, and supported horizontally in a gas furnace or over a series of Bunsen burners. The boat is slipped into the tube with a piece of thin platinum foil beneath it to prevent contact with the tube, if glass is used, and is left about 6 inches from the open end. The aspirator is set at work in order to draw a *gentle* current of air over the boat, and the furnace or burners are lit so as to heat the boat and an inch or so of tube beyond each end of it. The heat is raised as high as the tube, if glass, will stand without fusing, and maintained for some hours. When all combustible matter appears to be burnt off the burners are turned out, and the boat removed as soon as possible to the desiccator. When cool it is weighed, replaced in the tube, heated for twenty minutes, and cooled and weighed as before. If the two weighings agree the combustion is over, and the weight of the boat is deducted from the weight of the boat and contained ash. The weight of ash so found in a known weight of coal allows the percentage of ash in the coal to be calculated. If the two weighings of the boat and ash are not identical, the heating must be repeated until two consecutive weighings agree. The concordant weighings are taken for calculating the ash in the coal. The arrangement of the apparatus is shown in Fig. 1.

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* *Listy Chemické*, xii., 203.

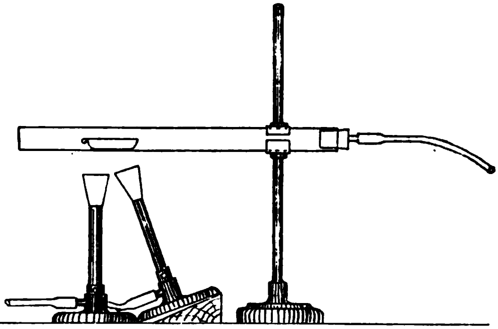


Fig. 1.—Apparatus for estimating ash by combustion in a gentle current of air.

In a still atmosphere the boat may project from the end of the tube instead of being placed within it. In that case a narrower tube is used, and the boat may be replaced by a piece of stout platinum foil bent boat-shape, and with one end doubled over to enter the tube. Two large Bunsen burners with flattened tops then play directly on the bottom of the foil, but should not be turned so high that the flame envelopes the contents, as free access of air is required for the combustion of the coal. Most coals require from six to eight hours to burn off

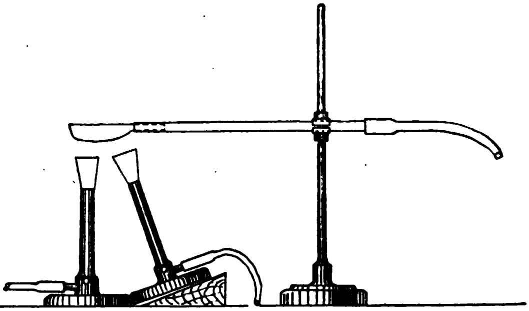


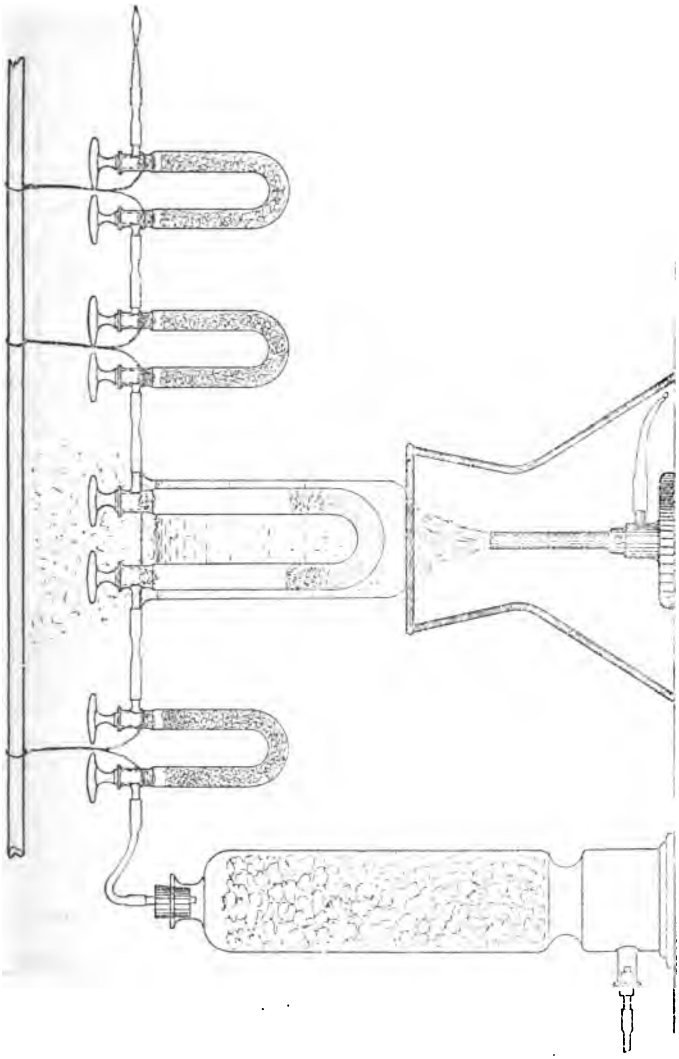
Fig. 2.—Apparatus for estimating ash by combustion in open air.

by this method; they should always be reheated for half an hour after weighing to ascertain if any further loss takes place, and in the event of a diminished weight the heating must be repeated as stated above. Two tests should be made on each sample, and if the results are within 0·5 per cent. of one another, the mean may be taken to correctly represent the amount of ash in the coal. The arrangement just described is illustrated in Fig. 2.

The ash in coal may be approximately estimated by gradually heating a weighed sample of the coal to redness in a muffle until the carbonaceous matter appears burnt off, cooling in a desiccator and weighing the ash. Where the yield of coke from a coal is accurately known, and a sample of the coke is available, the ash is more conveniently estimated in the latter, and the percentage on the coal calculated therefrom. The sample used for the estimation must be moderately free from moisture, or spirting and consequent loss on first heating will occur. The ash in coke is estimated by the methods described above for ascertaining the ash in coal. The amount of ash found on the large scale in furnaces is always greater than the laboratory test indicates, in consequence of some carbonaceous matter being retained in it owing to its partial agglomeration.

The composition of the ash is seldom investigated by a gas works chemist, except where the coke is used for lime burning or other purposes on the works. The amount of silica, alumina, ferric oxide, and lime are then ascertained by the ordinary methods. The amount of sulphur remaining in ash is more often determined. For the purpose, about 1 gram of the ash is accurately weighed, digested with *dilute* hydrochloric acid, filtered, and the sulphur estimated in the filtrate by precipitation with barium chloride in the usual manner. The percentage of sulphur in the ash is then usually calculated to percentage on the coke or coal for deduction from the total amount of sulphur in the latter, in order to ascertain the sulphur given off on combustion. Sulphur in ash is not detrimental to the value of a fuel.

Moisture in coal is not so readily determined with accuracy as is often supposed. When heated to 100° coal loses, but does not on continued heating attain a constant weight. The weight, after diminishing for some time, begins to increase, showing that an absorption of some kind is taking place. It is often recommended that a finely-powdered sample of coal should be dried in the water bath, being weighed at intervals, and the lowest weight obtained taken for the calculation of the percentage of moisture in the coal. But an error is certainly introduced here of unknown and varying magnitude, and the method cannot be



Fig, 3.—Apparatus for estimating amount of moisture in coal.

commended. The coal on first heating at 100° appears to lose certain volatile hydrocarbons as well as water, but afterwards appears to increase in weight through oxidation of the fine particles of which it consists. It is, therefore, necessary in an analysis of coal to adopt some other method of determining the amount of moisture. The most reliable is the weighing in a drying tube of the actual water driven off. The apparatus for the purpose is shown in Fig. 3. A stoppered U-tube having the hollows of the stoppers filled with dried cotton wool is weighed carefully while empty. The coal, in powder, is then put into the tube, and it is again weighed to find the amount of coal taken. Another U-tube is filled with lumps of calcium chloride (free from alkali) and weighed after displacing the air within by coal gas. A large tube of calcium chloride is connected to the gas supply, so as to remove all moisture from the gas passing through it. The U-tube containing the coal is suspended in a vessel of water which is kept in ebullition. The dried gas passes through this U-tube and then into the weighed calcium chloride tube, which is protected from access of moisture from the air by a small guard tube likewise containing calcium chloride. The dried gas is allowed to pass through the tubes for two or three hours, when the boiling water is removed, and the drying tube is in a few minutes closed by turning the stoppers, detached from the rest of the apparatus, and, after standing in the balance case or desiccator a short time, weighed. Its increase in weight represents the amount of water in the coal taken. The drying tube should be replaced, and the current of gas through the heated coal maintained for another half-hour, when the drying tube should be again weighed to ascertain if the whole of the moisture was driven off at the first operation. Dried air may be aspirated through the tubes instead of passing gas through, if more convenient. If gas is used, it may be burnt at a small jet connected to the last tube, and its rate of passage controlled thereby. The connections are made with *short* pieces of thick-walled caoutchouc tubing. If the U-tube containing the coal is weighed after the operation, it will generally be found to have lost more than the drying tube has gained in weight, especially if a current of gas has been used. It is well to place a weighed drying tube between the large drying tube and the U-tube containing the coal, to ascertain if the gas or air is perfectly dry.

The **density** of coal is generally referred to water at 60° F. as unity. It may be readily ascertained by two methods. In the first three or four representative pieces of the coal, each from 1 to 3 cubic inches in bulk, are weighed in turn, first in air and afterwards while immersed in water at 60° F. The difference between the two weighings represents the weight of the volume of water displaced by the coal, and consequently, if this is expressed in grams, approximately the volume of the coal in cubic centimetres. The weight of a certain volume of coal being known, and the weight of the same volume of water at 60° F. (the substance which is the unit of density), the specific gravity of the coal is found by dividing its weight by the weight of water at 60° F. it displaces. This is usually expressed by saying that the specific gravity is found by dividing the weight in air by the difference between the weight in air and in water. Certain precautions are necessary to obtain a correct result. The lump of coal should be carefully brushed before weighing with a dry camel's-hair brush in order to remove all dust and loose particles. It should be suspended for weighing by a hair or a silk thread looped round it. When immersed in water it must be again carefully but lightly brushed to remove all adhering air bubbles. As one lump is not likely to be a representative sample of the coal, the specific gravity of at least three pieces should be taken, and the average returned as the specific gravity of the coal.

The second method of taking the specific gravity of coal is by means of the specific gravity bottle, commonly used for determining the densities of liquids. A few grams weight of the roughly-powdered coal is put into the bottle and distilled water added until the coal is completely covered. It is then allowed to stand for ten hours to allow adhering bubbles of air to escape, and the coal to become "wetted;" this part of the procedure may be hastened by placing the bottle under diminished pressure by means of an air pump. The bottle is then filled with water, and weighed with the usual precautions exercised in taking the specific gravity of liquids, including the observation of the temperature of the water immediately after weighing. The weight of water at 60° F. contained by the bottle is, of course, known. Then the specific gravity of the coal is found by dividing the weight of coal taken, by itself less the difference between the weight of water and coal contained in the flask and the weight of water normally contained by it. Or expressed symbolically :—

$$\text{Specific gravity} = \frac{W}{W - (W_1 + W_2)} = \frac{W}{W - W_1 + W_2}$$

Where W = weight of coal taken, W_1 = weight of coal + sufficient water to fill the bottle, and W_2 = weight of water at 60° F. completely filling the bottle.

The **volatile matter** and **fixed carbon** in coal are sometimes determined in the laboratory, but the results obtained are at best only approximate. Several proposals have been made to render the determinations of value for comparative purposes by conducting them under certain fixed conditions. The most obvious plan is to heat the coal until all appearance of gas issuing from it ceases, and then to weigh the carbon (and ash) remaining. Unfortunately this method does not give a constant value, the variation with the same coal being as much as 3 per cent. Heinrich's test is more accurate and has been extensively adopted. About 2 grams of the roughly powdered coal is heated in a platinum crucible for three and a-half minutes over a Bunsen burner, which at the end of that time is changed for a large Bunsen with air blast, with which the heating is continued for a second three and a-half minutes. If the same burners are used for every test, and the time is measured accurately, the variations are slight, and the method gives good comparative results. Rather better is Lewis T. Wright's method. According to his instructions, 2 grams of the finely pulverized coal is taken in an even layer on the bottom of a thin platinum crucible, which is covered and heated by a powerful gas flame (maintained at the same height in all experiments). The heating is stopped one minute after gases cease to issue, the crucible is allowed to cool in the desiccator and weighed without the cover. The results are nearly constant for the same class of coal. When the volatile matter and fixed carbon are given in an analysis of coal, the method by which they were determined should invariably be stated, or the figures will be of little value. When the sulphur is determined in addition, the weight of volatile matter and fixed carbon should be corrected accordingly, and the moisture likewise should be deducted from the volatile matter.

The usual laboratory tests applied to coal have now been enumerated and described. The deductions which may be drawn from the results of such tests will be considered with the results of the **practical testing of coal** for yield of gas and coke under conditions approximating to those obtaining on the large scale in a gas works. A small plant, capable of working off a charge of a few pounds of coal, is generally fixed in the vicinity of the laboratory and a photometer room on the works. With judicious interpretation of the results, the tests are most useful, and enable judgment to be pronounced on a small sample of coal in a very short time.

The setting should consist of a cast-iron D-shaped retort, 3 feet in length, 5 inches wide, and 4 inches high, with direct firing, and dampers to the flues to regulate the draught. The retort should project about 4 inches from the setting, and be provided with a 2-inch ascension pipe leading to the condensing tubes, which may conveniently be attached to an adjacent wall.

Ten tubes, 7 feet in length and 1 inch diameter, form a suitable air condenser, if tolerably distant from the setting. Cocks should be provided for running off the tar and liquor into a trough beneath, and all the condenser tubes and the ascension pipe should be provided with a screw plug at top to be removed for cleaning at intervals, or when stoppages occur. The washer is usually omitted from this experimental plant, and the gas

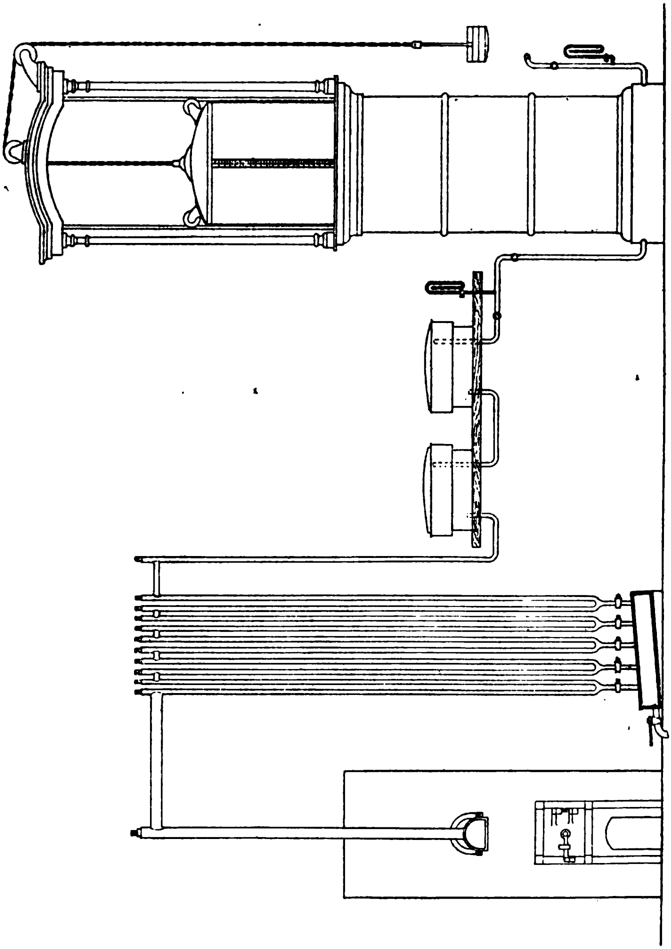


Fig. 4.—Experimental coal-testing plant.

passes directly from the condenser into the purifiers, which may be conveniently about 15 inches square and 8 inches deep, and contain two trays each charged with moist, slaked lime to the depth of 2 inches. The outlet of the second purifier leads to the gasholder, which should have a capacity of 15 cubic feet. An accurately graduated scale should be fixed to the holder to indicate the contents at any height in cubic feet and hundredths of a cubic foot. The outlet of the gasholder should lead into the photometer room and have a service to the photometer, and, if possible, one leading to the laboratory. Such an experimental plant is shown in Fig. 4. The charge commonly used is 2¼ lbs. of coal, which is approximately the thousandth part of a ton and is generally reckoned at that. It is, however, desirable to have a special weight of 2·24 lbs. (exactly $\frac{1}{1000}$ of a ton) kept for the purpose. Ordinary shop scales in good condition may be used for weighing out the charge. The latter, which should be a fair sample of the bulk, is carefully placed in a scoop about 30 inches in length. The retort should be at a bright-red heat, and the lid should be covered where it will touch the mouthpiece with damp clay, in readiness for closing the retort tightly. The apparatus should be cleared of air by a preliminary charge, the gas being driven back from the holder and burnt at the mouth of the retort, the ascension pipe being closed by a cock in it as soon as the holder is grounded. The charge is quickly put into the retort, the lid fixed and ascension pipe opened as quickly as possible. The holder should be weighted so that a pressure-gauge attached to the inlet pipe gives a level reading. The charge will take about twenty minutes to work off; if a pressure-gauge is attached to the inlet of the purifiers the end of the process can be readily seen by the absence of pressure when the holder is shut off. When no more gas is evolved, the cocks at the inlet of holder and on the ascension pipe are closed, and the coke is drawn from the retort into a clean iron vessel, in which it is allowed to cool without quenching, and then carefully weighed. The amount of tar and liquor in the condenser is best measured after several charges have been carbonized, and the amount from one charge calculated. The quantity of gas made is read off on the holder scale, the gauge being level at the time, and its temperature taken by a thermometer sunk in the crown of the holder. The volume is corrected to normal temperature and barometric pressure. The gas should remain a short time in the holder to mix thoroughly, and then be tested on the photometer for illuminating power, the service leading thereto being thoroughly cleared of other gas by burning the gas for half an hour prior to taking the readings. Much time is saved in the testing of coal by this experimental plant if it includes more than one holder, so that a charge can be worked off while the gas from a former charge is being tested.

The yield of gas obtained will be higher than may be expected on a large scale with the ordinary fire-clay retorts by about 3 per cent. For rich coals and cannels the retort should be as hot as possible, and care should be taken that a suitable burner is used for testing the gas. The sulphur in the gas may be estimated by Harcourt's or the Referees' method, as described in Chap. viii. The amount of coke will be virtually the same as that obtainable on the large scale. A sample of the coke should be reserved for the determination of its content of sulphur. The liquor will be deficient both in strength and quantity owing to the absence of proper scrubbing facilities. The illuminating power of the gas will be higher than may be expected in ordinary working with an exhauster and high heats. The product of the illuminating power, and the quantity of gas made, should be found and expressed either in candles per ton, or pounds of sperm per ton. The latter is the basis generally adopted, and is founded on the light evolved by sperm as consumed in the standard candle adopted by the Metropolitan Gas Referees. This candle has a consumption of 20 grains, or $\frac{3}{175}$ of a pound of sperm per hour. In testing, the gas is burnt at the rate of 5 cubic feet per hour, or corrections made to express the candle power at that rate nominally. Consequently the number of cubic feet of gas made per ton of coal must be divided by five to reduce them to their equivalent in lighting units. The number so found, multiplied by the candle power, and the result multiplied by $\frac{3}{175}$ (the lbs. of sperm per candle per hour), gives the value of the coal in pounds of sperm per ton. Or pounds of sperm per ton of coal

$$= \frac{\text{cub. ft. of gas per ton of coal} \times \text{illuminating power in standard candles} \times 3}{5 \times 175.}$$

Or, more briefly, the value of a ton of coal in pounds of sperm

$$= \text{cub. ft. per ton} \times \text{illuminating power in standard candles} \times 0{\cdot}00343 \text{ nearly.}$$

The results of tests of coal should be tabulated with as full details as possible. The following particulars should be stated in every case:—Weight of charge (unless a certain weight is invariably adopted); time occupied in working off charge; weight of coke obtained; coke calculated in lbs. per ton of coal carbonized, or percentage by weight on the coal; cubic feet of gas made; temperature of gas and barometric pressure; calculated volume of gas per ton of coal, corrected to normal temperature and pressure; illuminating power of the gas, tested against standard candles according to the Referees' instructions; and value of the gas from a ton of coal reckoned in pounds of sperm. At least six tests should be made with each sample of coal under investigation, and the average result calculated under each of the above heads. Further, the liquor and tar from three or more tests should be measured in fractions of a gallon, and the quantity of each per ton of coal calculated. The strength of the liquor by Wills' test (Chap. xi.) should be ascertained, and the amount per ton of coal calculated into the equivalent number of gallons of 10 ozs. strength, which is the standard strength generally adopted. Since, however, the measurement of the tar and liquor made on a small scale is accomplished with difficulty, and the results are not accurate, it is very commonly omitted in coal testing. In the laboratory, tests should be made to furnish the following particulars:—The specific gravity of the coal; the percentage of moisture in the coal; the total sulphur in 100 parts of the coal, and in 100 parts of the coke; the volatile sulphur—*i.e.*, sulphur yielded to the gas, calculated from these figures and the percentage yield of coke; the percentage of ash in the coke; the percentage of ash in the coal, calculated from the above and the known yield of coke, or estimated directly; the percentage of moisture in the coke. With the exception of the estimation of sulphur and moisture in coke, which is treated in the next section (p. 26), the methods of making the above tests have been described. The gas is often examined directly for impurities and various constituents; the tests applied will be found described in Chapter viii.

The following examples will indicate the method of tabulating results, and the figures that may reasonably be expected from certain kinds of coal (see p. 23).

Coal that has given satisfactory results in the small experimental plant described above and in the laboratory testing is frequently tested on an ordinary working scale before being purchased in quantity. For this purpose a small plant of from one to six full-sized clay retorts is erected and furnished with the usual apparatus of scrubbers, exhausters, purifiers, &c., in size proportioned to the number of retorts. The whole plant constitutes a diminutive gas works, and can be readily erected by the constructing engineer so as to resemble as nearly as possible in working the ordinary settings and plant of the particular works. Provision should be made for close observation of the manufacture, and the careful measurement of the quantities of gas, liquor, tar, and coke yielded. For convenience of testing, such an experimental plant should be near to a photometer room

DESCRIPTION OF COAL.	Weight of each Charge.	Time in Working off.	Coke. Percentage by Weight.	Gas made per Ton of Coal, Corrected Volume.	Illuminating Power. Candles.	Pounds of Sperm per Ton of Coal.	Gallons of Liquor, 10 Ozs. Strength.	Specific Gravity of Coal.	Moisture in Coal.	Sulphur in Coal.	Sulphur in Coke.	Volatile Sulphur in Coal.	Ash in Coal.	Ash in Coke.	Moisture in Coke.
	Lbs.	Mins.		Cub. ft.					°/o	°/o	%	%	%	%	%
Lesmahagow Cannel,	2·24	23	46·3	11,888	31·22	1272·5	19·5	1·21	2·13	0·83	0·85	0·44	7·02	15·20	2·1
Durham Caking Coal (1), . .	2·24	21	69·9	10,616	16·88	614·4	25·4	1·27	2·21	1·71	1·98	0·32	5·11	7·31	3·2
Durham Caking Coal (2), . .	2·24	25	71·4	10,382	14·75	525·0	26·1	1·29	3·71	1·51	1·03	0·74	7·88	11·03	2·7
Silkstone (Yorkshire),	2·24	28	63·0	10,512	15·90	573·0	26·3	1·27	2·02	1·13	1·01	0·49	4·85	6·90	4·3

and laboratory. The results obtained will be strictly comparable with those furnished with the larger plant of the gas works, but in general slightly less favourable to the coal. On the other hand, the small iron retort installation gives a higher illuminating power than gas made on the works from similar coal would possess, and a deduction from the iron retort figures under this head of about 4 per cent. will give the probable result to be attained in ordinary working. The reduction of illuminating power on the large scale is due to the thorough scrubbing the gas receives, some of the illuminants being washed from it thereby. In comparing results of working on the large and small scale, it must be remembered that heat passes more rapidly through the iron than through the clay retort, and that the latter can be worked at a higher temperature than the former. The candles per ton, or pounds of sperm per ton, increase slightly with the volume of gas made, and consequently with the heat employed in carbonization, within the limits of customary gas works temperatures. The amount of work done per retort, or per mouthpiece, if through retorts are employed, or per superficial foot of interior surface of retort, if the size of the latter is not uniform, is the best guide to the proper degree of heat to be employed in carbonizing to obtain the highest value from a given coal. These general indications of the considerations which determine the selection or rejection of a sample of coal for gas making will suffice for the present purpose.

ANTHRACITE, COKE, &c.

Incandescent carbon decomposes water vapour with the production of equal volumes of hydrogen and carbonic oxide. If the carbon is not at a sufficiently high temperature, another action takes place resulting in the formation of carbonic acid and hydrogen. The gas produced by the first reaction is known as water gas, but in practice it is usually contaminated by small quantities of carbonic acid produced by local occurrence of the second reaction owing to unequal or insufficient temperature of the carbon. As the carbon is the active material in the production of water gas, it is evident that the ideal substance for the manufacture is pure carbon. This is unobtainable in quantity and at a price consistent with economical production of gas on a large scale, consequently the manufacturer must be content with the most highly carbonaceous fuel to hand at a low price. The particular fuel which fulfils this condition will depend on the local conditions, but in comparing fuels it must be remembered that their value for water gas manufacture is almost solely determined by their carbon content. The density of the fuel and the nature of its other constituents affect its value for the purpose in a less degree.

Anthracite.—Certain varieties of coal known generically as anthracite contain a large amount of carbon, and consequently rank as suitable materals for water-gas production. They do not show very great variation in composition or in physical properties, and occur in extensive deposits in many parts of the world. Anthracite may be regarded as the ultimate natural decomposition product of woody fibre, and generally exhibits no traces of the forms of the plants from which it was derived. Eliminating the ash or residue remaining on combustion, the percentage of the chief constituents of anthracite is:—Carbon, 90 to 95; hydrogen, 2 to 4·5; oxygen, 2 to 5. The specific gravity varies from 1·3 to 1·9, generally being about 1·40. The amount of ash left by anthracite is usually less than 5 per cent. of its weight. Immense deposits of anthracite are found in the United States, especially in Pennsylvania. This anthracite is close and compact, has a specific gravity of about 1·45, and contains from 2 to 10 per cent. of ash. It is largely used for the production of water gas. On an average it will contain 91 per cent. of carbon. Anthracite is found in large quantities in South Wales. It is less dense than that from Pennsylvania, its average specific gravity being 1·35. As a rule, it does not contain more than 2 per cent. of ash, and its percentage of carbon is about 91. Other localities where anthracite occurs in tolerable quantities are France, Saxony, Chili, Brazil, and South Russia.

Coke.—When the volatile matter is removed from bituminous coal by destructive distillation, the residue consists almost entirely of carbon, and the inorganic bodies which will remain as ash on its combustion. This residue known as coke is produced in large quantities as a bye-product in the manufacture of coal gas, and also is made in specially constructed ovens on a large scale for metallurgical purposes. The products of the two processes differ somewhat both in composition and in physical properties. The ovens in which coke is produced as the main product are much larger than gas retorts, and some forms are worked at a higher temperature, while in others a more prolonged exposure to heat is given. Considerable modifications of the original forms of ovens have been made of late years to enable ammonia and tar to be recovered as bye-products, and the properties of the coke produced have been slightly affected thereby. It is, however, more compact than gas coke and contains less sulphur, and consequently supersedes the latter for metallurgical uses. For the manufacture of water gas it is hardly likely to come largely into use, though it would serve well. Gas coke being a bye-product, can generally undersell oven coke, and especially where water gas is made for addition to coal gas, the coke produced in the manufacture of the latter is ready to hand for the production of the former. It must be remembered, however, that gas coke is inherently less suited for making water gas than anthracite or oven coke, and that its employment requires a deeper generator, and greater expenditure of time and labour on clinkering. It is evident that coke for gas making must be as free from ash as possible, but where a water-gas plant is subsidiary to a coal-gas installation, it is of necessity of a quality dependent on the coal used in the latter. The best coke from the retorts should, however, be invariably used, and the percentage of ash contained in it should not in any case exceed 10. It should be in lumps of uniform size, 2 to 3 inches in diameter, all dust and breeze being carefully screened from it. Coal that is fit for gas making will not give as a rule coke containing an excessive amount of sulphur, and as the latter will be present in the water gas mainly in the form of sulphuretted hydrogen, its removal from the gas will not cause difficulty. The coke must be free from excess of moisture; it should not lose more than 2 per cent. in weight on heating for three hours at 100° C. The ash in coke is estimated by the method described on p. 12.

The total **amount of sulphur** in coke is estimated by the gradual heating of about 2 grams of the finely-powdered coke with four times its weight of mixed alkaline carbonates, to which, when in a state of fusion, twice its weight of potassium nitrate is slowly added. The mixture is kept in a state of fusion for a few minutes longer, then allowed to cool, and extracted with dilute hydrochloric acid, and the sulphur precipitated and weighed as barium sulphate in the manner described in Chap. viii. Stolba's method for the determination of sulphur in coal (p. 12) is applicable to coke, the heating being continued a few minutes longer. The results are accurate. It is customary to deduct from the sulphur in coke the amount of sulphur in the equivalent quantity of ash, to obtain the amount actually given off on combustion. The method of determining the amount of sulphur in an ash is given on p. 14. The sulphur in coke, which is evolved as sulphur dioxide on its combustion, may also be directly estimated. A weighed amount of coke is roasted in a boat within a combustion tube in the manner described for the estimation of ash on p. 12, but a bulbed tube containing solution of bromine or iodine is placed between the combustion tube and the aspirator. The products of the combustion of the coke are thus drawn through the solution, and any sulphur dioxide present is oxidized by the halogen to sulphuric acid, which can be afterwards estimated in the usual manner. A known volume of standard iodine solution may be used in the bulbed tube, and titrated with standard solution of thiosulphate after the combustion of the coke is completed. The loss of iodine by the standard solution shows the amount of sulphur dioxide oxidized, and from that the amount of sulphur can be calculated. This method is rapid of execution if the standard solutions are at hand. The following equations show the reactions involved:—

$$SO_2 + I_2 + 2H_2O = H_2SO_4 + 2HI.$$
$$I_2 + 2Na_2S_2O_3 = 2NaI + Na_2S_4O_6.$$

The **specific gravity** of coke is not often determined. It may be ascertained by slight modifications of the methods given for coal on p. 17, the vacuum pump being used to remove air bubbles adhering to the coke when submerged.

Anthracite is tested for impurities, &c., in precisely the same manner as bituminous coal.

Pure Carbon.—Of experimental interest only is the use of almost pure carbon for gas making. Where quantities of retort scurf are at disposal, it may be broken to lumps of 4 to 8 cubic inches, and used in the water-gas generator either alone or mixed with coke. When broken sufficiently small, and with the use of a powerful blast, it forms an excellent material for manufacturing pure water gas. Being practically pure carbon, it is wholly combustible, and gives a gas free from impurities. Its limited production and value for other purposes forbid its use on a large scale.

OIL.

Petroleum.—Chief among liquid hydrocarbons available for the production of illuminating gas is petroleum or earth oil. This natural product of the decomposition of vegetable and probably animal remains varies greatly in character and composition, and consequently in fitness for gas making. In many cases the crude oils as extracted from the earth may be used without preliminary treatment, but as certain distillates and the residuum from processes worked for the purpose of obtaining oil suitable for other ends frequently serve for gas manufacture, the subject naturally divides itself from the gas manager's point of view under two heads:—(1) Crude oils; (2) the products of distillation or treatment of crude oil or oil-bearing rock.

The **origin of petroleum** has for years been a subject of controversy among experts, and even now opinions are divided.

Here it will suffice to say that the bulk of petroleum appears to be of vegetable origin, though strong evidence of the presence of animal remains exists in many cases. By the heat of the earth destructive distillation of the vegetable or animal remains deposited in certain strata has ensued, and the distillate has found a convenient storage in the sand rocks whence it is now obtained. The rocks in which the oil had its origin are termed shales, and belong for the most part to the Devonian age. The deposits generally underlie the coal strata, and there is abundant evidence that the petroleum is not a product of the action of heat on the coal deposits, a convenient theory of its origin much espoused some years ago. A feature of the oil-bearing rocks is their contiguity to mountain ranges; the oil districts lying almost universally a short distance from the foot of extensive ranges of hills and running parallel to them. This association of productive oil fields with mountains is well illustrated by the oil districts of Pennsylvania, California, the Caucasus, and Galicia. The oil frequently flows out at the earth's surface, in obedience to the laws of hydrostatics, by reason of the pressure exerted by the oil contained in adjacent rocks of greater elevation; or, in other cases, where quantities of gas are stored in the natural reservoirs above the oil, the latter may find an outlet in some spot below the level of the gas by reason of the expansive force of the gas exerted on the surface of the oil. In general the oil is obtained at the earth's surface by boring and pumping; if the boring strikes the upper part of the cavity, gas only escapes for some time. This natural gas, stored up in the oil-bearing rocks, has been extensively used in the United States for lighting and heating, but in some cases the supply is now failing, and towns hitherto dependent on it are forced to erect installations of gas making plant. The natural gas consists chiefly of methane, and hence is especially valuable for heating purposes. The oil as it issues from the wells varies in colour and consistency according to the locality, but in general is of a deep, dirty green colour by reflected light, and reddish-brown by transmitted light. The specific gravity varies very considerably; the lightest oils usually come from deep wells.

Distribution.—Petroleum is found in large or small amount in almost all parts of the globe, but the chief oil-bearing districts are enumerated below:—

In the south of Russia, from the Caspian to the Black Sea, is an immense oil field, which extends eastwards to Afghanistan. The oil is heavy, having a specific gravity from 0·850 to 0·885, and frequently contains water, and a large amount of solid matter in suspension. The town of Baku on the Caspian is the centre of the oil industry of the district, and the bulk of the oil raised is distilled there. The Balakhani fields, the most productive of the neighbourhood, are about eight miles from Baku, whither the oil is conveyed by pipe-lines. There is a railway from Baku to Batoum on the Black Sea, to which port the oil is taken in tank wagons for shipment to other countries in tank steamers. The United States of America embrace several oil districts, the most important of which is the Pennsylvanian field, which stretches from the State whence it takes its name northwards into New York State. The oil varies in specific gravity from 0·770 to 0·880, and varies considerably in colour, green and deep amber prevailing. The Bradford field is the most prolific in this district. The State of Ohio has large oil deposits; the most important being that of the Lima field. This oil is black, has a specific gravity from 0·820 to 0·840, and contains much sulphur. The crude oil is very extensively used in the manufacture of carburetted water gas. There are also oil districts in Wyoming, Illinois, Kentucky, Indiana, West Virginia, and many other parts of the United States. Californian petroleum is worked chiefly for local use, and has a specific gravity of about 0·840. In Canada there is a field of about 200 square miles in Ontario. The oil from it is black and largely charged with sulphur compounds, the specific gravity is from 0·830 to 0·880. There are large oils fields in Peru, and other parts of South America. Peruvian oil varies from 0·785 to 0·835 in specific gravity. In Mexico oil very similar to that of Pennsylvania is found. In Europe there are extensive fields in Galicia and Hungary. The specific gravity of Galician petroleum ranges from 0·800 to 0·900. In Hanover and other parts of Germany oil is found. Japan, Burmah, India, and Persia contain oil deposits which are worked to a small extent for local use. Petroleum is also found in Egypt and Algiers, but it is heavily loaded with sulphur.

The **chemical composition** of petroleum has not been sufficiently made out to enable definite conclusions to be drawn from the results at present obtained. But it is certain that it differs very considerably according to the locality from which the oil is derived. Thus petroleum from one district will be largely made up of hydrocarbons of one series, while petroleum from another district will consist chiefly of homologues of a totally different series of hydrocarbon compounds. The nature of the bulk of the hydrocarbons in an oil largely determines the products obtained from it on destructive distillation, consequently a brief statement of the composition of the chief varieties of petroleum, as far as present knowledge admits of it, is given. Pennsylvanian petroleum consists chiefly of hydrocarbons of the paraffin series, the lowest members of the series, methane and ethane, though gaseous, are found either in close association with it or even dissolved in it. Thence, there have been isolated from it all the normal hydrocarbons of the series up to $C_{13}H_{28}$, as well as several isomers and some higher members. The aromatic hydrocarbons, benzene and its homologues, are present in very small amount, if at all, in the original petroleum. They are found in distillates as products of (local) destructive distillation. Very small quantities of naphthenes and olefines are found in American (Pennsylvanian) petroleum.

Russian or Caucasian petroleum consists chiefly of homologous hydrocarbons known as naphthenes. These are isomeric, but not identical with the olefines. Markownikoff and others have isolated these hydrocarbons from Balakhani petroleum from C_7H_{14} to $C_{15}H_{30}$ inclusive. They are isomeric and probably identical with the hexa-hydrogen addition compounds of the hydrocarbons of the aromatic series. Some of the members of the aromatic series, notably some having the general formulæ $C_{10}H_{14}$ and $C_{11}H_{16}$ have been found in Russian oil, as also hydrocarbons of the acetylene series ($C_n H_{2n-2}$). Olefines have been found in small amount, but paraffins are virtually absent.

Galician and German petroleums consist chiefly of paraffin hydrocarbons, with smaller quantities of hexahydrobenzenes, and other aromatic hydrocarbons. Olefines are scarcely found in these oils.

The chief gas-making oils belong to one of these three classes, with the exception of the oils distilled from bituminous shale in Scotland and elsewhere. Unlike any of the above, this shale oil contains a notable quantity of olefine hydrocarbons, mixed with smaller amounts of paraffins.

Gas-making Petroleums.—Some few oils are available for gas making in their natural state, but the bulk of crude oils require distillation before use. In the United States certain oils, such as that of the Lima field, are used without treatment in the carburetted water-gas plants, but these are not available in this country. Russian crude oils leave, as a rule, too much solid residue on distillation to be used for gas making in the ordinary forms of apparatus. But in the distillation of crude petroleum and shale for the production of burning and lubricating oils, certain fractions of the distillate cannot be relegated to either of these classes, and are reclaimed from the category of waste products only by their suitability for gas manufacture. Thus, a bye-product in the manufacture of illuminating oil avails for the manufacture or enrichment of the rival illuminating agent—gas. The essential points of a good gas-making petroleum are freedom from water, and from solid residue on distillation, and reasonably small content of sulphur compounds. The specific gravity and volatility of the oil are of importance, but can only be considered in relation to the particular form of apparatus in which it is to be used. The flashing point is indirectly of importance in indicating the precautions to be observed to prevent inflammation during transport or storage. The burning point test has a similar import. The nature of the hydrocarbons constituting the oil is to be considered with the practical test of the amount and quality of gas yielded by it, and can only give general indications of the most suitable method and temperature to be employed in the manufacture.

Method of Examination.—The laboratory examination of an oil to determine its fitness for gas making embodies the operations described hereunder. The specific gravity of the oil and its temperature at the time of taking the specific gravity are ascertained. A hydrometer with an open scale serves for taking the specific gravity if the instrument is known to be correctly calibrated. The scale should be sufficiently open to allow reading accurately to within 0·0005; and the thermometer should be in the oil when the reading is being made, and be read immediately after the hydrometer. Failing the use of an accurate hydrometer, the specific gravity must be taken in the ordinary way with a specific gravity bottle, but the high coefficient of expansion of petroleum renders careful and rapid working necessary, and care is requisite to obtain the temperature of the oil at the time of weighing correctly. By either method it is desirable that the specific gravity should be taken at the standard temperature, usually 60° F., but as this is generally impossible it should be corrected to that temperature by means of the coefficient of expansion of the oil, which may, in general, be taken at 0·00036 per degree Fahrenheit as an average value for petroleum oils. Oil is frequently bought and sold by weight, which is calculated from its volume and specific gravity, hence the accurate determination of the latter has special importance in many cases.

The flashing point of burning oil is determined in this country by the apparatus devised by Sir Frederick Abel and adopted as the standard by the Board of Trade. For oils of low flashing point it is equal, or superior, to any of the forms of apparatus adopted in other countries. A description of the method of making a determination with it is given with each apparatus, and there will be little divergence in the results obtained by different operators if the directions are implicitly followed.* Most oils suitable for retorting have, however, fairly high flashing points, and the determination can be made with sufficient accuracy in a much simpler apparatus. This consists simply of a cylindrical copper vessel, about 3 inches in diameter and 3 inches deep. The lid overlaps the top of the cylinder, but a flange ¾ inch deep attached to it fits within the cylinder, and keeps the lid in position. The lid is perforated in two places; one hole is for the insertion of the thermometer held by a perforated cork fitting the orifice, the other is covered by a small lid pivoted to the cylinder cover, so that the opening can be exposed by sliding the lid from it, and can be covered again immediately after each application of the test-flame. The oil to be tested fills the cylinder to a height of 2 inches, and the bulb of the thermometer is immersed in the liquid when the cover is in position. Heat is applied to the bottom of the cylinder by means of an Argand burner, or a sand bath, so that the temperature of the oil rises about 1° F. per minute. As each degree on the thermometer scale is reached the opening in the cover is exposed, and a small gas flame passed over it. If no flash is observed, the opening is closed until the next trial is made. The temperature at which the flash is first observed is noted, and recorded as the flashing point of the oil. If it is wished to confirm the result, a fresh portion of the oil must be taken for a second determination, as oil that has once flashed will not again flash at its original flashing point. The gas flame used for testing should be ⅜ to ½ inch in length, and is readily obtained by fusing the end of a piece of hard glass

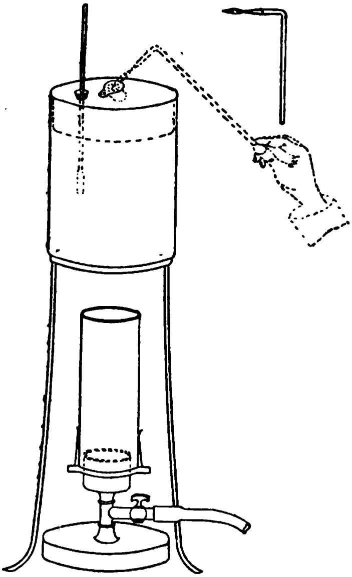


Fig. 5.—Oil flashing point apparatus.

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* Details of the apparatus will be found in Redwood's *Treatise on Petroleum* (Charles Griffin & Co., Ltd.), where also the method of using is fully described.

tube until the orifice allows only sufficient gas to pass through at its ordinary full pressure to give that length of flame. For accurate determinations heating the cylinder in a water or oil bath may replace direct heating by an Argand burner. The apparatus should be protected from air currents during the determination. It is illustrated in Fig. 5. The flashing point is usually stated in the Fahrenheit scale in this country.

The distillation of a sample of oil gives much valuable information as to its properties. For most purposes it may be conveniently carried out in the laboratory in the manner here described. A glass spheroidal flask with a glass tubulure fused in its neck, of capacity twice the volume of the oil to be distilled is taken, and a thermometer is inserted in the neck by means of a tightly-fitting perforated cork, so that the bulb of the thermometer is on a level with the mouth of the tubulure. The latter is connected to a Liebig condenser. The neck of the flask is lightly held by a clip, and the bottom rests on wire gauze, while the sides of the flask are jacketed with the same material to protect them from air currents. Heat is applied by means of an Argand or rose burner at first, though towards the end of the distillation a Bunsen may be needed. A convenient quantity of oil for distillation is 500 or even 250 c.c. The flask should be weighed before and after the oil is put in it, and thus the weight of the oil taken is known. The heat should be regulated so that the distillate *drops* from the end of the condenser at a uniform rate, and does not come from it in a stream. The temperature is read on the thermometer when the oil begins first to pass over, and afterwards as each fraction of the distillate is removed. The distillate is usually collected in fractions amounting to 10 per cent. of the volume of oil under distillation. The specific gravity of each fraction is ascertained approximately. The distillation is pushed until increased heat drives over no more oil, and no residue, or coke only, remains in the flask. When cool the flask is again weighed, and the weight of the residue so found enables its percentage (by weight) on the oil to be calculated. The weight of each fraction of the distillate can be found by direct weighing, or from the specific gravity. The total of the weights of the distillates and the weight of the residue should amount nearly to the weight of oil taken, the deficiency, which should not exceed 1 per cent., may be recorded as "loss on distillation." It is due to some of the more volatile distillate escaping condensation. With many oils it is desirable to use two thermometers—one for temperatures from 20° to 150° or 200° C., the other (nitrogen filled) for higher temperatures. A thermometer which has been used at high temperatures is not accurate for low ones. The amount of water, if any, which comes over, and settles beneath the oily distillate, should be observed. The colour of each fraction should be recorded, and a piece of moist lead paper held above the outlet of the condenser at intervals to find if sulphuretted hydrogen is evolved at any stage of the distillation. The degree of blackening gives an indication of the amount of sulphur in the oil. A note should be made of all observations, and the results of the distillation should be recorded in the manner indicated by the record of the distillation of a typical Russian gas oil given on p. 38. The determination of the amount of sulphur in gas oil is seldom made, but can be carried out by Carius' method, or by a slight modification of the fusion methods for sulphur in coal, or by burning the oil in a suitable lamp, and passing the products of combustion through a washer of hydrogen peroxide or other suitable oxidizing agent, and estimating the sulphate as the barium salt. (*Cf.* the Referee's method of estimating sulphur in gas by burning, as described in Chap. viii.)

A good oil for gas making should be free from water, and leave less than 1 per cent. of coke on distillation. A crude oil will generally contain fractions distilling below 100° C., but the distillates now so largely employed for gas making will be free from so light fractions. A natural oil generally contains water, though sometimes only in small quantities, and there is great divergence in the boiling points and specific gravities of the fractions of distillate from it. Rapid blackening of lead paper should not take place until near the end of the distillation. Only the tenth fraction should be decidedly dark in colour. Oils containing more residual coke than 1 per cent. may be used in certain methods of oil gas manufacture, but are not desirable in any plant containing chequer work chambers or small outlet pipes. Provided the distillation results do not condemn an oil, it is tested for yield and quality of gas in a small oil-gas apparatus. It is not of great importance which of the numerous forms of apparatus in common use is adopted, but the same should be used during a series of experiments, and comparisons made with tests of a standard oil in it. Paterson's, Keith's, Pintsch's, or Avery's apparatus may be used; Chapter v. should be consulted for details of manipulation. The apparatus should be of a size to work off a gallon of oil in about three hours. The heat of the retort or tubes must be regulated according to the nature of the oil under trial; tests should be made at different temperatures to find that most favourable to the oil. The temperature should be observed with a Le Chatelier or other good pyrometer, but where this is impossible a practised eye can judge it with fair accuracy. Not less than a gallon of oil should be gasified at each test; the gas should pass through two lime purifiers (2 feet square by 1 foot deep, two shelves) and then through a meter, the index of which should be read before and after the test to find the quantity of gas made. The temperature of the meter should be observed several times during the experiment, and the mean temperature and mean barometric pressure taken for correcting the volume of gas to normal conditions. From the meter the bulk of the gas passes to a works holder, but a small stream of it is led to a 15- or 20-feet holder for testing purposes. The pipes should be thoroughly cleared of air before this sample is collected, and the stream should be such that the holder is filling throughout the test. The sample is tested for illuminating power in the ordinary way, but it will generally be necessary to try several burners to find that most favourable to the oil. The highest candle power found with any burner should be taken for calculating the value of the oil. The method of testing for illuminating power is described in the Chapter on Photometry. Care must be taken that the gas in the small holder is thoroughly mixed; if there is any doubt about its being so the whole of it should be burnt in the photometer, tests taken at regular intervals, and the average of these tests taken as the illuminating power. As a general rule, American oils give the best results at a lower heat than shale oils, and the latter at a lower heat than Russian oils. The results of the tests should be calculated out to give the number of candles produced by the gas from a gallon of oil burning at the rate of 1 cubic foot per hour. As the standard rate of 5 cubic feet per hour is too fast for oil gas, the candle power at the actual rate of consumption is taken, and the nominal candle power at the standard rate arrived at by calculation (see Chap. ix.). The product of the number of candles at the standard rate, and the volume of gas per gallon of oil divided by 5 (the number of feet burnt per hour at the standard rate) gives a figure which represents the "candles per gallon" obtained from an oil. This figure multiplied by $\frac{3}{175}$ (see p. 21) gives the pounds of sperm per gallon of oil. The pounds of sperm per gallon divided by the specific gravity of the oil, and the result divided by ten, gives the pounds of sperm per pound of oil. The results of oil tests are usually stated either in "candles per gallon," or "pounds of sperm per pound" of oil. The method of tabulating the results is shown by the examples on p. 39.

Several well-known and fixed grades of oil have been thoroughly tried for gas making. Of these certain Russian distillates have come into special favour in this country on account of their good qualities and low price. In the distillation of crude oil at Baku about 5 per cent. of benzine and gasolene is obtained, and then about 27 per cent. of oil fit for the manufacture of burning oil. The residue is not always distilled further, but is disposed of for liquid fuel under the name of **astatki** or **masut.** But where lubricating oils are manufactured the distillation is pushed further, and a fraction amounting to about 15 per cent. of the crude oil, and having a specific gravity of about 0·870, is next obtained. This is known as **solar oil**, and being too heavy for use as an ordinary burning oil and too fluid for lubricating purposes, it was till recently a drug on the market, and was generally used with residues as fuel. This has a flashing point of about 200° F., and is, therefore, particularly suited for transport to a distance. This oil, or a distillate from it, has been recently extensively used for gas making, and gives excellent results. The lubricating oils distil over after the solar oil, and amount to over 30 per cent. of the crude oil. About 15 per cent. of residue, which is used as fuel, remains in the still, the quantity of oil unaccounted for having been lost as vapour or otherwise during distillation. Solar oil for gas making should be free from water, have a specific gravity from 0·860 to 0·885, and a flashing point from 120° F. to 250° F. The residue of coke left on distillation does not usually exceed 0·5 per cent. of the weight of the original oil. When distilled, it begins to pass over at a temperature of 130° C., and the early distillates are nearly colourless. The remainder are pale straw to amber, the last only being deep brown. Very little sulphuretted hydrogen is evolved during distillation. The details of an actual distillation are given on p. 38. Solar oil works best at a medium red heat, or at about 900° C., and at that temperature gives in most forms of pure oil gas apparatus a yield of about 1,150 candles per gallon.

From the Scotch shale distilleries comes an oil of very similar grade, unsuitable for burning or lubricating, and largely used for gas making. This intermediate shale oil has a specific gravity from 0·840 to 0·870, and its flashing point is generally above 150° F. It does not begin to distil over under 120° C., generally at about 150° C. The distillates are nearly colourless, and the residue of coke is less than 1 per cent. on the oil. The oils are generally amber or pale brown in colour, and with a strong green or blue fluorescence. Sulphuretted hydrogen is evolved tolerably freely during the distillation. The oil gives the highest result at a rather dull heat, but if the gas is to be subjected to great pressure or cold, a bright red heat must be used to obtain a maximum yield of permanent gas. At a moderately dull red heat, about 800° to 900° C., a good Scotch intermediate oil yields about 1,200 candles per gallon. The crude parafin oil from the shale stills is not suitable for use in most forms of apparatus.

In the United States of America certain crude oils are extensively used for gas making. The specific gravity is about 0·830. As the oil flashes at or little above the ordinary temperature, it is unsuited for transport to a distance. It gives the best result at a moderately low heat. In consequence of the much larger yield of burning oil, American oils produce less intermediate oil on distillation than Russian petroleum.

The results of tests made on typical gas oils are given at the close of this Section. With the exception of petroleum, few oils are worthy of consideration for gas making. The price of animal and vegetable oils is prohibitive; the only others available are the dead tar oils. As tar is a product of destructive distillation at a high temperature, it is evident that it will not be greatly altered in character by exposure to a high heat. A considerable portion will merely volatilize and condense again unchanged on contact with a cool surface. The light benzene hydrocarbons will act thus, likewise naphthalene and other closed-chain hydrocarbons. The green oil from coal tar, which remains after the extraction of phenols and naphthalene from the middle oils of the tar distiller, contains a certain amount of gasifiable hydrocarbons, and is sometimes used for gas making. A high heat is required to produced a permanent gas from it, and the illuminating power is always low. Coal tar "green" oil yields about 350 candles per gallon. Oil tar as deposited in the condensers and syphons of an oil gas installation contains about a quarter its volume of intermediate oil which, when separated by distillation and freed from naphthalene, may be put through the apparatus to produce gas. The yield is, however, only about 300 candles per gallon, and the gas is of dubious permanency.

RESULTS OF THE EXAMINATION AND DISTILLATION OF A SAMPLE OF RUSSIAN GAS OIL.

The oil was of the class known as "Solar" distillate, and was of a clear, deep amber colour, with a green fluorescence. The specific gravity was 0·8705 at 60° F., and the oil flashed at 210° F. One litre (measured at 60° F.) of the oil was taken for distillation in a glass tubulated retort, the distillate being collected in fractions of 100 c.c. (10 per cent. of the volume of the oil). The flask used weighed 244·6 grams.

No. of Fraction.	Approximate Volume.	Colour, &c., of Fraction.	Limits of Temperature between which the Fraction Distilled over.	Specific Gravity at 60° F. of Fraction.	Weight of Fraction	Percentage by Weight on the Original Oil.
	c.c.		° C.		grams.	
I., ...	100	Clear, colourless; no water	126 to 242	0·8205	82·05	9·43
II., ...	,,	Clear, colourless	242 ,, 266	0·8490	84·90	9·75
III., ...	,,	,, ,,	266 ,, 285	0·8565	85·65	9·84
IV., ...	,,	,, ,,	285 ,, 297	0·8605	86·05	9·89
V., ...	,,	,, ,,	297 ,, 308	0·8655	86·55	9·94
VI., ...	,,	,, ,,	308 ,, 319	0·8705	87·05	10·00
VII., ...	,,	,, ,,	319 ,, 330	0·8755	87·55	10·06
VIII., ...	,,	Clear, tinted	330 ,, 346	0·8800	88·00	10·11
IX., ...	,,	Clear, pale straw	346 ,, 366	0·8870	88·70	10·19
X., ...	94	Clear, brown	366 ,, 395	0·9005	84·65	9·72
Solid Residue (see below),	...	...	...	...	2·70	0·31
Loss on Distillation = .	...	...	...	...	...	0·76
						100·00

The flask after all the volatile matter had been expelled, weighed 247·3 grams. Deducting from this the net weight of the empty flask, the weight of the residue is found to be 2·7 grams. It was of the nature and appearance of a friable, porous coke. Sulphuretted hydrogen could be detected in the vapours of the 9th fraction, and was readily observed towards the close of the distillation.

RESULTS OF GAS MAKING TRIALS OF VARIOUS OILS.

DESCRIPTION OF OIL.	Its Specific Gravity at 60° F.	Volume of Gas made per Gallon of Oil. At 60°F. and 30 ins. Cubic Feet.	Average Illuminating Power, with most fit Burner, calculated for a Consumption of 5 Cubic Feet per Hour. Standard Candles.	Candles per Gallon of Oil.	Pounds of Sperm per Pound of Oil.	Mean Temperature of Retort.
Russian solar distillate,	0·873	81	63·25	1024	2·01	Medium red heat (about 900° C.)
Russian solar distillate,	0·884	104	52·9	1100	2·13	Bright red heat (about 1,000°C.)
Scotch shale oil,	0·855	91	66·2	1205	2·41	Medium red heat (about 900° C.)
Scotch shale oil,	0·862	111	47·2	1048	2·09	Bright red heat (about 1,000°C.)
American paraffin oil,	0·801	85	66·3	1137	2·43	Dull red heat (about 780° C.)
American paraffin oil,	0·833	103	55·75	1148	2·36	Medium red heat (about 900° C.)
Oil tar distillate,	0·987	65	21·25	276	0·48	Bright red heat (about 1,050°C.)

CARBURINE AND OTHER LIGHT OILS.

In the distillation of crude petroleum for the preparation of burning and lubricating oils, a certain amount of very volatile liquid is usually obtained in the early stages. This is kept apart from the burning oil, the flashing point of which it would lower unduly. At one time of very limited use as a solvent, &c., and frequently left to run to waste, or burnt beneath the stills, it is now extensively used for enriching poor gas or carburetting air. The most volatile fractions condensed from American petroleum are known as **cymogene** and **rhigolene**; the former is only obtained by condensation in ice, and is stored with difficulty in air-tight vessels capable of resisting considerable pressure; the latter is the next higher fraction, and boils at about 14° C. These fractions are so difficult of transport on account of their extreme volatility that they do not find their way into the market for carburetting purposes. Practically the **carburine** which finds its way on to the market in such large quantities is a mixture of all the hydrocarbon distillate from American petroleum which comes over under about 160° C., and is condensable by ordinary means. Besides some rhigolene or petroleum ether, it contains **gasolene** and **benzine**, as the next higher fractions are called. **Ligroin** and **petroleum spirit** are names given to the next higher distillates, and the carburine commonly used for gas enriching is made up of more or less of each of these products. The chief constituents of these light petroleum products are, as may be anticipated from their source, light paraffin hydrocarbons. Gasoline consists chiefly of pentane, with smaller amounts of butane and hexane. Carburine has a far larger proportion of hexane, and appreciable quantities of higher homologues. Gasoline boils at about 38° to 42° C., and carburine at from 60° to 75° C. The specific gravity of the carburine in general use varies from 0·675 to 0·700, averaging about 0·680.

Mixtures of light unsaturated hydrocarbons do not appear to have been practically used for carburetting. Recently, however, benzene, and more commonly one of the commercial mixtures known as 90 or 50 per cent. benzol, have been advocated as agents for cold carburetting. Up to recently it was generally supposed that gas could not carry a sufficient volume of the vapour of benzene to render this hydrocarbon of practical service; but experiments and theoretical considerations unite to demand recognition for it. Benzene boils at 80·5° C., and has a specific gravity of 0·885 at 15° C. 90 and 50 per cent. benzols contain toluene, which boils at 110° C., and has a specific gravity of 0·871 at 15° C. The xylenes are also present in commercial benzols in small quantity, as well as traces of non-aromatic carbon and some sulphur compounds. The benzene mixture most in favour for carburetting is "90 per cent. benzol," which contains about 70 per cent. of benzene and 25 per cent. of toluene (see Chap. xi.). This mixture distils almost wholly between the temperatures of 82° and 112° C. Its specific gravity is generally from 0·882 to 0·885.

It is evident that the number of substances practically available for carburetting is very limited, and their respective merits are easily determined. There is a limit to the amount of vapour of any hydrocarbon that a gas can hold at any given temperature, expressed by the vapour tension of the hydrocarbon at that temperature. Practically, therefore, the gas must give the desired illuminating power when the vapour of the enriching hydrocarbon is not present in it to the saturation limit at any temperature to which the gas will probably be exposed. Prudence and experience both indicate that it is well to work with a very wide margin in this respect. At 32° F. the vapour tension of benzene is 25·3 mm. of mercury, which is equivalent to a percentage of 3·3 volumes of benzene vapour in gas at 760 mm. and that temperature. Gasoline (chiefly pentane) will mix with gas to the extent of 10·7 per cent. by volume, and carburine (hexane principally) to 8·0 per cent. by volume at 32° F. These materials have very different enriching values, according to their differing molecular composition, and at present their values are found empirically. They will be considered in the chapter on Enriching by Light Oils (Chapter vi.) from a working standpoint. Some useful deductions, both from theoretical and practical data, are to be found in a paper by Mr. T. S. Lacey in the *Transactions of the Incorporated Institution of Gas Engineers* for 1892,* and in an article by Dr. H. Bunte in the *Journal für Gasbeleuchtung* in 1893, p. 442.†

* *Journal of Gas Lighting*, vol. lix., p. 903.

† Abstracted in *Journal of Gas Lighting*, vol. xlii., p. 717.

CHAPTER II.

COAL GAS.

Retorts.—The ordinary gas manufactured in the gas works of England is made by the destructive distillation of coal in retorts externally heated. The dimensions, shape, position, and material of the retorts used have varied considerably since the early days of gas making, and even now the opinions of engineers are at variance as to the correct answer of questions bearing on some of these points. In the matter of material there is now small latitude, fireclay of some description being invariably used. The iron retorts of the early days of gas manufacture are incapable of resisting the high heats now prevalent, and the cost of renewals alone would be prohibitive. They are no longer found, except in small experimental works. Fireclay retorts are manufactured in many parts of the country, those from Stourbridge being especially well known. The shape and size of the retorts differ with the description of setting adopted. Where the retorts are set horizontally in works of moderate or large size, they are about 20 feet in length, with a mouthpiece attached to each end. They are burnt in three (or sometimes four) portions, one end of two of the portions being provided with a flange for the reception of the mouthpiece, the middle portion having flush ends for joining up to the outer sections in the setting. The customary cross-section of retorts is D-shape, the flat side forming the bottom of the retort when set. Occasionally retorts of oval or even circular cross-section are used, but do not give such high results in gas made, though some engineers consider the oval-shaped retorts rank with the D-shaped in this respect. The usual dimensions of the D-shaped retort are:—Extreme width internally, 20 inches; extreme height internally, 13 inches; thickness of walls, 3 inches; length, 20 feet—made up in three sections. Retorts having a cross-section 22 inches by 16 inches are, however, now common. The flange for the mouthpiece is 4 inches thick, and extends 9 inches on the retort. In small works the retorts are usually only half the length of the above, and have one end closed. They are usually burnt with the ends open, and in one piece, the back being put on in the setting. They are adopted only where the number of stokers does not allow of charging from both ends simultaneously. Wherever this is possible, though 20-feet retorts are used, as they are more economical of heat and give less trouble in scurfing. Specially designed retorts are required when they are not set horizontally; these will be briefly noticed when inclined settings are considered. The retort mouthpieces are always of iron, and generally of the same cross-section as the retort, though occasionally they are made for a D-shaped retort and a circular lid. The back of the mouthpiece carries a flange, by which it is bolted to the retort, with a packing of some suitable cement, often a mixture of fireclay and iron turnings. In the top of the mouthpiece is the socket for the lower end of the ascension pipe. The front of the mouthpiece is faced to receive the lid, which is likewise faced. Several self-sealing retort lids have been devised — that of Mr. Morton being very largely adopted. Luting is unnecessary with self-sealing lids, and in Morton's design, with Holman's eccentric bolt fastener, manufactured by Tangyes, Limited, the lid is not removed from the mouthpiece on opening, but swings round on a hinged cross-bar. On closing the lid, turning the lever actuating the eccentric bolt, forces the faced surfaces of lid and mouthpiece into air-tight contact. This design of mouthpiece and self-sealing lid is shown, for D-shaped retorts, in Fig. 6. The old-fashioned lid and mouthpiece had lugs projecting from the latter, to one of which the cross-bar was hinged, the other having a notch into which the free end of the cross-bar fitted. Through the middle of the cross-bar passed a screw actuated by a cross handle, to force the lid down on to the planed lip of the mouthpiece. These lids required the use of luting material to make a tight joint, and have now been almost entirely super-

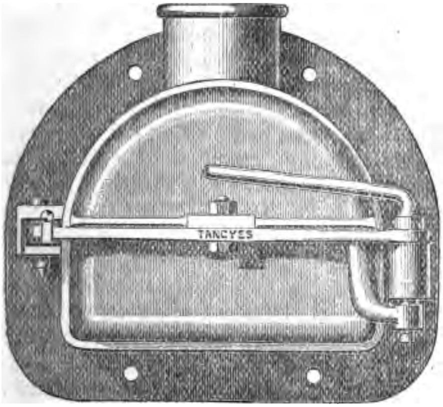

Fig. 6.—D-shaped mouthpiece, with Morton's self-sealing lid.

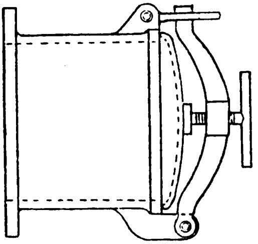

Fig. 7.—Mouthpiece and lid, old pattern.

seded by self-sealing ones. Fig. 7 shows this old style of mouthpiece and lid. Several patents have been taken out for self-sealing lids, but the simplicity and ease of working of Morton's pattern, described above, have brought it into very general use, and space will not allow of other designs being described.

Mode of Setting Retorts.—The retorts are usually set in benches of from three to nine, or even twelve, heated by one furnace. In large works nine retorts are generally put in each bench, though sometimes the number is only seven or eight. The retorts are supported by the front walls of the ovens, and a number of transverse walls built in the oven. The number of these varies in different settings, but the retorts very commonly have supporting walls about 2 feet apart throughout their length. The dimensions and arrangement of the oven vary not only with the number of of retorts in the bench, but also with the description of furnace adopted. Generator furnaces on the regenerative principle are now almost universally used, but the number of systems of applying it is legion. In some few works direct firing is still in use, but it is uneconomical of fuel. In others a compromise is made by using a shallow generator and admitting a small supply of secondary air. Regeneration has been frequently condemned on the score of the saving of fuel being insufficient to compensate for the greater outlay of capital on the settings than in plain generator furnaces. This charge against regenerative settings was well founded in the case of many of the more complicated systems, which involved a large capital expenditure, but was not justified as far as those of simpler construction were concerned. A simple arrangement of flues and air passages may involve a small sacrifice of efficiency over a more complicated design, but the loss is more than compensated by the reduced cost of erection. Regenerative retort settings have formed the subject of innumerable patents and considerable litigation, but many of the more important patents have now expired, and the principles involved are common property. The Siemens' regenerative furnace was first tried, but the changing of the valves, though apparently a matter of ease, proved troublesome, and it was generally regarded as too complicated for economical working. The continuous system of recuperation as distinct from the alternating one of Siemens was applied by Laming to heating gas retorts with some measure of success. Sir W. Siemens took up the Didier furnace, and it was largely used; Valon altered the Liegel somewhat, and it became well known as his own. Other furnaces of notoriety were the Schilling and Bunte and the Klönne. The regenerative furnaces in use in this

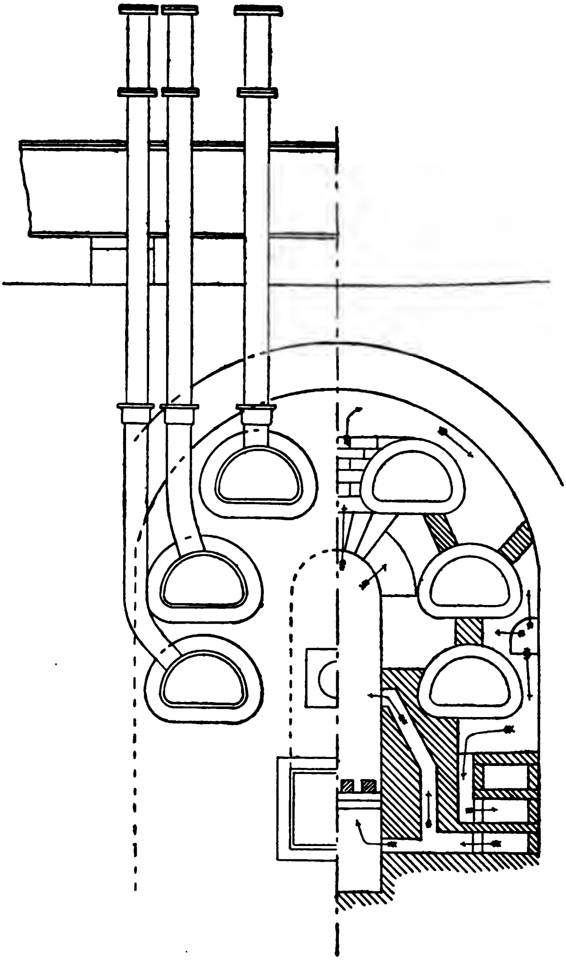

Fig. 8.—The Klönn

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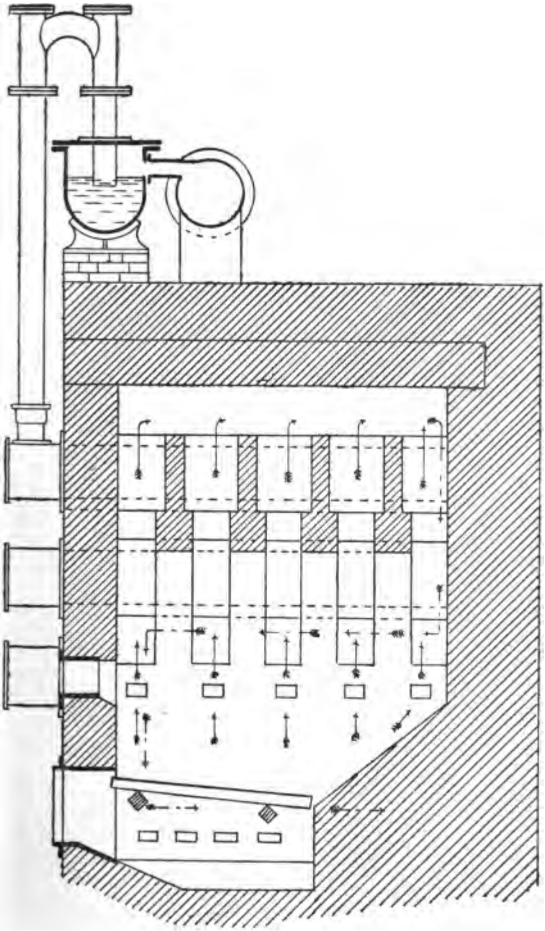

nne-regenerative furnace.

country, though often not precisely on any one of the above-named systems, must in general be regarded as modifications of one or more of them. Those in which the generator is quite detached from the settings have been discarded, and the tendency now is to have a separate furnace for each bench of retorts. The designs of the Klönne and Hasse-Didier, as well as of a furnace in use in some of the London works, are shown in Figs. 8, 9, and 10 respectively. Hislop's regenerative setting is much used in some parts of this country, and is, like many of the above-mentioned settings, still protected by letters patent.

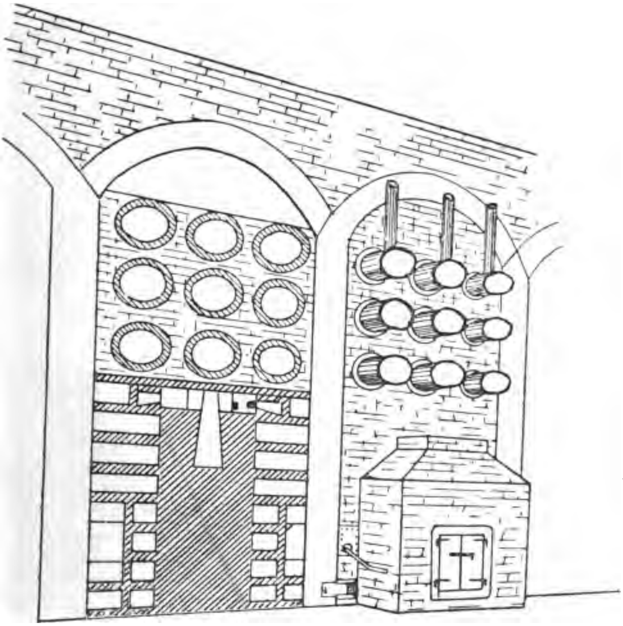

Fig. 9.—The Hasse-Didier regenerative furnace.

Spent Gases.—The waste gases or products of combustion from the furnaces, after passing through the flues to impart a portion of their heat to the air supply, where the regenerative system is in use, pass into a main flue running throughout the length of the stack, and thence up a shaft terminating a short distance above the roof of the house. When complete combustion is not taking place in the furnaces, the carbonic oxide burns on coming in contact with the air at the top of the shaft,

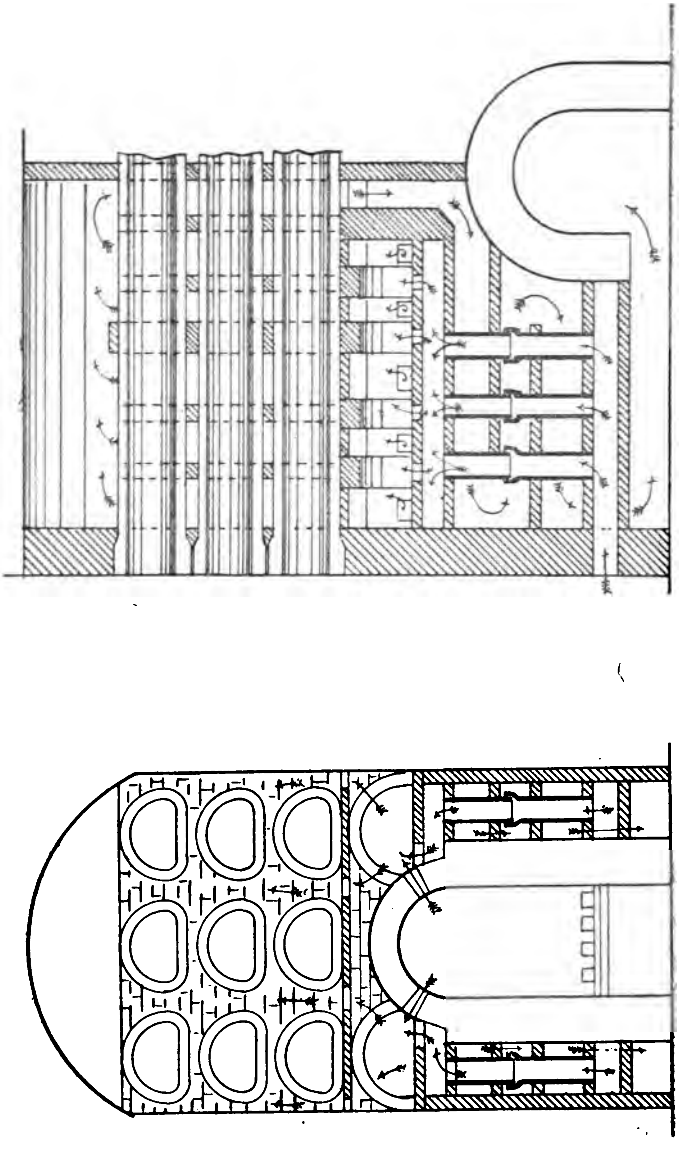

Fig. 10.—Furnace used in some London works.

producing the flame too often observed there. This is a sure indication of improper working of the furnaces, and the supply of secondary air should be increased to ensure combustion of the whole of the carbonic oxide produced in the generator under the retorts. But this rough indication of bad working is not sufficient to form the sole guide of the engineer to the proper amount of primary and secondary air to admit to the furnaces. A sample of the spent gases should occasionally be drawn into a gas-burette by means of a piece of iron gas pipe 3 or 4 feet in length. The end of the pipe inserted in the flue should be plugged, and the gas admitted by several small perforations extending a few inches up the sides of the pipe. The pipe may with advantage be lined internally by inserting in it a platinum tube of such size as will conveniently fit it, and correspondingly perforated. The end of the platinum tube projects a few inches beyond the open end of the gas pipe, and is connected by flexible tubing with the gas burette. The gas is drawn into the burette by connecting the nozzle with an aspirator. A Bunte burette serves well for collecting and examining spent furnace gases. The analysis of the gas is carried out according to the methods given in Chapter viii. If the combustion is perfect, and the supply of air not in excess of that required to give perfect combustion, the analysis should show 21·0 per cent. carbonic acid. This would be attained by the combustion of generator gas having the composition required by theory for it—viz., 34·7 per cent. carbonic oxide, and 65·3 per cent. nitrogen. In practice this perfect generator gas is never formed; hydrogen is always present in it from the decomposition of the steam given off from the water in the ash pans, besides a small amount of methane; while the conversion of carbonic acid to carbonic oxide in the upper part of the bed of fuel is never complete, and some of the higher oxide remains in the gas. For the more thorough control of the working of generator furnaces, the generator gases should be analysed as well as the spent gases. The percentage of carbonic oxide should be as little below 30 as possible; if it approximates to that amount the working may be considered very good. It may vary somewhat according to the percentage of hydrogen in the gas, but the amount of carbonic acid present should never be allowed to exceed 6 per cent. The spent gases should as nearly as possible consist wholly of carbonic acid and nitrogen; the amount of carbonic oxide should be *nil*, and the amount of oxygen 1 or 2 per cent. only. The proper regulation of the air supplies to attain these conditions will result in great economy of fuel, and should be strictly enforced throughout the works. These figures are very seldom actually attained but should always be aimed at; commonly producer gas contains about 22 per cent. of carbonic oxide and 8 per cent. of carbonic acid; and the spent gas as much as 5 per cent. of oxygen.

It has been assumed that coke is the fuel used for heating the retorts, but in some works where direct firing is in vogue tar has partially replaced solid fuel for the purpose. It is either allowed to burn on an inclined plate on to the upper part of which it is dropped slowly, or it is injected through specially constructed nozzles with air or steam. In most systems of burning liquid fuel used in this country, a small amount of inferior solid fuel, such as breeze, is burnt with it and forms a fuel bed. Where the state of the market favours the use of tar as fuel on the works, it is more often consumed under the boilers than in the retort furnaces. The lid of the generator is frequently so placed that the coke may be fed directly into it as the retorts are drawn, thus saving the loss of heat on quenching.

The **retort stack** is constructed of firebricks set in fireclay, or fire-resisting cement, in all parts adjacent to the furnace or hot-gas flues. Stourbridge and Dinas firebricks are in common use, but gas engineers are by no means united in opinion as to the best variety of brick for the purpose. The cements used differ considerably also in composition; some are intended for use alone, others require the addition of a certain proportion of lime before use.

The Welsh fireclays contain a much higher percentage of silica than those of Stourbridge and Newcastle; in the former it is from 93 to 97, in the two latter about 65·0.

Furnace-Bar Cooling.—A pan of water is always placed under the furnace bars. The heat from the fire and from the falling cinders vaporizes the water, the steam passes up into the furnaces and is decomposed by the incandescent carbon, yielding the hydrogen found in the generator gas. The steam passing through the furnace bars serves also to keep the latter cool, and to moderate the effects the intense heat of the fire would otherwise have upon them. The water in the ash pan is renewed at the rate at which it vaporizes.

Charging and Drawing.—The working or charging stage is situated about a foot below the level of the lower tier of retorts, and generally above the top door of the generator, which is then charged from the basement, though sometimes the lid of the generator is on the level of the stage and carried forward to admit of charging direct with the glowing coke from the retorts. Space is left between the stage and the settings for the dropping of the coke as it is drawn from the retorts to the basement, where it is quenched and loaded into waggons.

The stage is left clear for a width of 12 or 15 feet where the charging of the retort is done by hand, and the space from that point to the walls of the house serves for the storage of coal. From this store of coal, running the whole length of the house on each side of it, the scoops and shovels for charging are filled. The coal is often shot in the house from hopper waggons traversing an elevated railroad. In charging by hand a scoop of semi-circular section, and in length half that of the through retort, is used. It is fitted with a T-handle, as shown in Fig. 11, and a piece of bar iron known as the saddle, shaped as in Fig. 12, is used for raising the opposite end of the scoop. The scoop is laid lengthwise on the stage and filled from the adjacent coal heap, the handle end is then raised by one stoker, the saddle is then placed under the opposite end of the scoop by two other stokers, who, one on each side, raise it to the mouth of the retort, when the saddle is withdrawn and the scoop is thrust in and overturned by the stoker in charge of the handle. It is then withdrawn, refilled, and again carried to the retort, being overturned on the opposite side of the retort to the former scoopful. Three or four shovelfuls of coal are then usually added and the retort closed. It will be seen by this description that three stokers are required to charge a mouthpiece with the scoop. The chief stoker who holds the handle and manipulates the scoop is known as the scoop-driver. Through retorts must be charged at both ends simultaneously, there fore they cannot be used with fewer than six stokers. The scoop holds about 1¼ or 1½ cwt. of coal, consequently about 3 cwts. constitute the charge per mouthpiece. The lids of the retort are closed immediately the full charge is in it, and from four to six hours elapses before the coke is drawn out. The time occupied in burning off the charge varies with the description of coal, the heat of the retort, and the quality of gas required. Five hours is a common allowance, though six is very general in the London gas works. With the latter time and with high heats, practically no gas remains in the coke; but the average quality of the gas made is poor, and if ordinary bituminous coal is used the candle power is only 12 to 14. Consequently enrichment must be cheap, or the regulations as

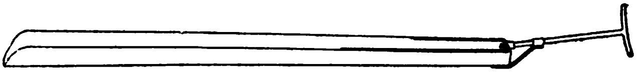

Fig. 11.—Scoop for hand-charging of retorts.

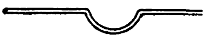

Fig. 12.—Saddle for raising scoop.

to quality not exacting, to make such a system remunerative. The amount of the difference between the pressure within the retort and the barometric pressure, also exercises an important influence on the quality and quantity of the gas made from a given quantity of coal. This point will be discussed more fully later. At the expiration of the allotted time for the working off of the charge, one stoker loosens the lever on the lid of the retort, while a second holds with a pair of tongs a piece of red-hot coke to the edge of the lid to ignite the gas remaining in the retort as the lid opens. The gas then burns away quietly, whereas if the lid is thrown open suddenly cold air rushes in, and combines with the contained gas with explosive violence, thereby shaking the settings. The noise of the explosion renders carelessness in opening the retorts easy of detection. The coke is withdrawn from the retort by means of a long-handled rake; in the case of through retorts half is drawn from each end. A piece of sheet-iron called a "fender," fixed to a suitable framing, is placed at the edge of the charging stage to prevent the coke scattering on to the latter, and to direct it downwards to the basement of the house, where it is quenched as rapidly as possible by directing water from a hose on to it. It is there kept for firing the generators, or loaded into waggons for conveyance to the coke store. In some few instances the lids of the generators are on the level of the charging stage, and the firing is done with the hot coke as it is drawn from the retort. The retorts should be charged again as soon as possible after drawing.

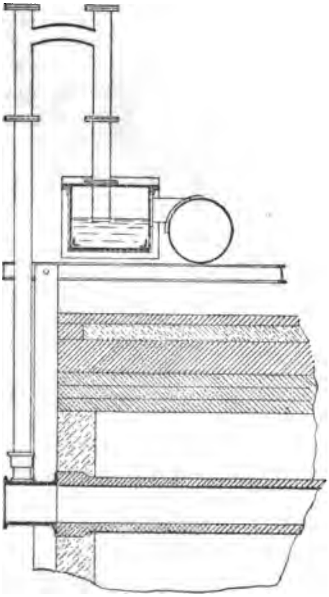

Fig. 13.—Sectional view of ascension pipe, bridge and dip pipes, and hydraulic main.

Exit Pipes.—The upper part of the mouthpiece has a socket for the reception of the lower end of the ascension pipe, which forms the means of exit for the gas from the retort. The ascension pipe is usually 5 inches in diameter internally, and is straight or bent, according to the position of the retort in the setting. At its upper end it joins the bridge pipe, which is of the same diameter, and runs horizontally for about 2 feet towards the middle of the stack. Here it joins the dip pipe, running vertically downwards into the hydraulic main, which runs the whole length of the stack. The bridge pipe often is in the shape of an inverted **V**, and the tops of the ascension and dip pipes project above the junctions with the bridge pipes, and have the ends closed by plugs, which can be removed for cleaning purposes should the pipes become badly blocked. The ascension pipe, the bridge and dip pipes, and the hydraulic main, in section, are shown in Fig. 13.

Hydraulic Main.—The hydraulic main is usually square or oblong in cross-section, and is now usually constructed of mild-steel plates. Wrought iron is still used, but the day of cast-iron hydraulic mains is past. They were extremely heavy, and liable to crack on sudden changes in temperature. The main runs along the top of the retort bench, and receives the dip pipes, which are sealed by the liquid in the bottom of the main. This consists of tar and ammoniacal liquor deposited from gas that has previously passed through. The depth of seal commonly adopted is about ¾ inch, though frequently it is greater. The layer of liquor floating above the tar should be sufficiently deep to maintain the requisite seal, as contact of the gas with tar is deleterious to the quality of the former. In this country it is very common to divide the hydraulic main into several sections, each with an outlet for the gas, which passes into a large main running the whole length of the house, at the back of the hydraulic main, known as the foul main. This arrangement presents considerable advantages when some sections only of the house are at work, or when repairs are necessary to some portion of the hydraulic main. Many mechanical devices for taking the place of the water seal of the hydraulic main have been proposed, but have not, up to the present, presented an alluring aspect to English gas engineers.

Condensers.—From the foul main the gas passes to the system of condensing pipes, usually situated outside the retort house. In some cases, however, the pipes have been carried round the walls of the house, so as to avoid a sudden lowering in temperature of the gas. In the more common plan the condensers are placed at a short distance from the retort house, though, even in this matter, instances may be adduced in which the gas traverses several hundred yards of main between the house and the condenser. The main is usually laid beneath the ground, so that no large amount of condensation takes place in it. The form of condenser most favoured in this country is a system of nearly horizontal pipes, exposed to the air, and in hot weather cooled by water sprayed on to them. The main bringing the gas from the retort house enters a short cross main, to which from two to twelve condensing pipes of 6 to 12 inches diameter (the number and size being proportioned to the make of gas) are connected. These pipes run side by side, slightly inclined to the horizontal, and are commonly from 50 to 80 feet in length. The gas passes along these pipes, and thence along a similar series of pipes ranged beneath the former. From these it passes along another similar series beneath the last; an ordinary condenser will have from eight to twelve rows of pipes so arranged—one beneath the other. A slight inclination is given to all the pipes, so that the condensed matters may run to the outlet at the lower end of the condensing pipes. All the pipes in the bottom row lead into a cross main, the outlet of which goes to the exhauster or washers. The gas entering the condenser passes the whole length of it as many times as there are pipes in each vertical row; the number of pipes side by side being so fixed as to enable them to pass the whole of the gas at a slow rate in sufficiently small streams to expose it freely to the inner surfaces of the pipes, the outer surfaces of which are in contact with the air. A view of this type of condenser is given in Fig. 14.

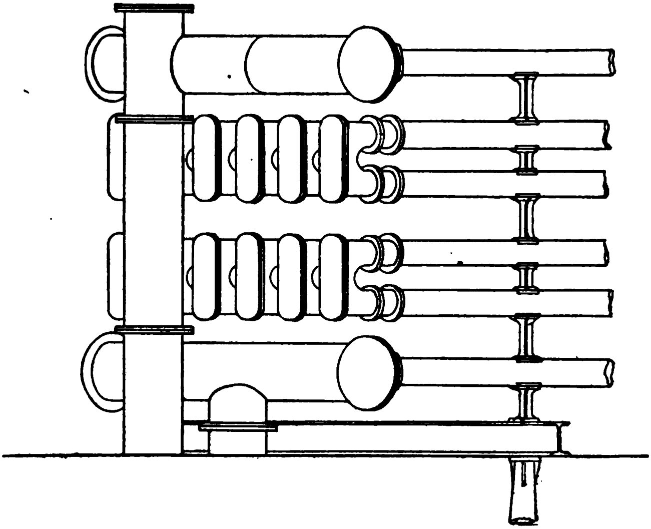

Fig. 14.—End view of horizontal condenser.

It is evident that this and indeed all atmospheric condensers are efficient in proportion to the superficies of the pipes, and, consequently, these should be of as small diameter as is consistent with working with freedom from stoppages from accumulations of tar. About 6 inches internal diameter has been found to answer this requirement in large works. The total length of pipe through which each stream of gas should pass is largely determined by its rate of flow. At the temperatures prevailing in this country, and with water sprayed on to the condenser in summer, from 150 to 200 square feet of condensing surface should be allowed for each thousand feet of gas passing per hour. The calculations should be based on the maximum make of gas. The hot gas entering the top pipes first and, gradually becoming cooler as it descends, induces currents of air to pass upwards among the condensing pipes, and the lower pipes which the gas enters after parting with much of its heat are continually surrounded by air at the atmospheric temperature. Strangely enough, a recently erected condenser in a large works has the course of the gas reversed—*i.e.*, the gas enters the lowest tier of pipes first. Some other instances of this arrangement may also be found. In old works vertical condensers are frequently still found, but they are less efficient than the horizontal form. They consist of a number of pipes, 20 to 30 feet long, placed vertically side by side. The gas passes up one pipe and down the next throughout the series. The condensed matters pass out at the lower ends of the pipes into a cistern, small partitions sealed by the liquor directing the course of the gas in the cistern, unless a separate cistern is attached to each pair of pipes. Many condensers have been devised in which water either partially or wholly replaces the air as the condensing medium. A horizontal condenser has been immersed in water, which is withdrawn and replaced continuously; or, as in Cutler's pattern, a small tube passes throughout the interior of the condensing pipes, and conveys a stream of water in the opposite direction to that of the current of gas. These devices have not found great favour, and where space is not limited the horizontal atmospheric condenser has held its own. It must be borne in mind that coal gas condensers have not been designed to effect as rapid a cooling of the gas as possible, but rather to bring the gas to the atmospheric temperature by easy gradations. The reason for this at first sight unscientific and uneconomical procedure will be discussed later.

Exhausters.—In most works the gas passes from the condenser to the inlet of an exhauster. The exhauster is designed to draw the gas from the hydraulic main and condensers, and so to reduce the pressure both within these and also in the retorts. It also serves as a pump to force the gas through the washing and purifying apparatus to the holder. Several types of exhauster have been proposed, but those in most general use at the present day are based on Beale's design, which is similar to that of a rotary engine produced by Ramella in 1588. This has undergone many modifications to adapt it especially for use as a gas exhauster. As now usually made, it consists of a cylinder with closed ends set with its axis horizontal, and having inlet and outlet gas ports on the opposite sides of its lower half. Within this is a smaller cylinder set eccentrically to the outer one, and with its outer surface in contact with the interior surface of the larger cylinder at its lowest point. On a pivot fixed in the axis of the outer cylinder revolves a block, sliding within guides attached to two blades which extend to the inner surface of the outer cylinder. A steam engine, generally horizontal, is used to turn the exhauster; the slides forcing the gas from one side, where the inlet is, to the other side of the cylinder, where the outlet port is situated. The axle bearings are outside the cylinder. A section of this pattern of exhauster, as made by Messrs. Bryan Donkin & Co., in accordance with Beale's 1877 patent, is given in Fig. 15. An improved form, in which the capacity of the inner cylinder is also utilized for pumping, was patented in 1892, and described by E. Bryan Donkin in his paper, read before the Incorporated Gas Institute in 1893. He claims for this that in addition to possessing increased capacity it steadies the flow of gas, and does away with the pulsations of the ordinary exhauster. The pulsating action of the common

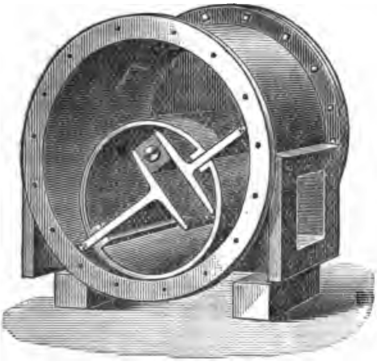

Fig. 15.—Beale's gas exhauster, patented in 1877.

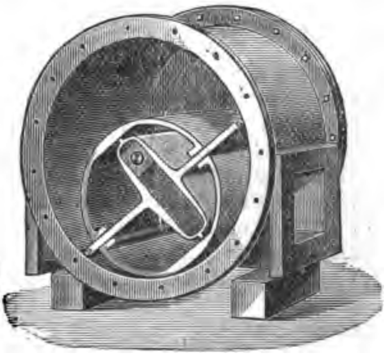

Fig. 16.—Donkin's improved Beale's gas exhauster, patented in 1892.

pattern may be neutralized by using two exhausters, revolving with the slides at right angles to one another, or by passing back some of the gas from the outlet to the inlet pipe to equalize the pressure, but the uneconomical nature of the latter plan is condemnatory. For most purposes on a gas works the pulsating action of the exhauster is not of great importance. Donkin's improved form of Beale's exhauster, patented in 1892, and made by Messrs. Bryan Donkin & Co., Ltd., is shown in Fig. 16. In other forms of the rotatory exhauster there are two slides partially overlapping, and guided to maintain contact with the surface of the outer cylinder, by segments running in grooves in the end plates of the exhauster. Exhausters in which toothed wheels geared together revolve on parallel axes in a casing have been used, as also have fans for pumping gas, but practically these have been superseded by Beale's pattern. The lubrication of exhausters working immediately after the condensers is almost sufficiently effected by the tar deposited from the gas, but this may be supplemented by the introduction of tar oil when necessary. Exhausters pumping clean gas are best lubricated by a good machine oil free from sulphur impurities and perfectly fluid at low temperatures.

An exhauster has been devised by Cleland, in which high-pressure steam is projected through a series of inverted truncated cones increasing in size progressively, and slightly overlapping. The gas is drawn in at the spaces left between the segments, and is carried on by the steam. The latter is afterwards removed by condensation. This pattern, as made by Körting Brothers, has been used on the Continent. Reciprocating exhausters, of which many were devised, were less steady in action than rotatory, and have given place to the latter.

Inclined Retorts.—The production of gas in horizontal retorts having been so far considered, and its course to the exhauster traced, it is desirable to retrace our steps and to consider briefly inclined retorts. These are worked in this country under the patent rights acquired by the Automatic Coal-gas Retort Company, Limited. Trial settings have been erected in very many works, and in a few they are permanently established. Usually the retorts are about 15 feet in length and D-shaped, and are set at angles varying from 29° to 36° to the horizontal. They are generally arranged in two benches about 20 feet apart, the retorts sloping downwards to the stage between the benches. They are charged from elevated stages at the sides of the house, the coal being allowed to run into the retort from a hopper. Various mechanical contrivances for conveying the coal to the hoppers and transferring it thence to the retorts have been tried with more or less success. The difficulties of charging are not great if the retorts are set at the correct angle of repose for the particular coal in use. This angle naturally varies somewhat with the nature and degree of fineness of the coal, and has long been a subject for discussion. In some settings the retorts of the lower tier are set at a smaller angle than those of the upper. A levelling-plate has been used for spreading the coal evenly in the retort, but the heat to which it is subjected quickly renders it pliable, and useless until cooled. The angle most generally approved is from 31° to 32°, and at this most kinds of coal lie in a fairly even layer, and the coke falls out with tolerable readiness. The coke should fall out completely when the lower lid of the retort is opened, and the layer is gently pulled by a rake. Retorts increasing in width gradually towards the lower end have been used to facilitate the discharge of the coke. Where the retorts slope towards the middle of the house, the coke can readily be run into trucks or to a conveyor passing through it. The furnaces are generally charged from the front of the bench, and may be merely modifications of ordinary regenerative or simple settings. The Coze setting, designed specially for inclined retorts, has been largely used on the Continent and has given satisfaction. With it the retorts are set at about 29° to the horizontal. The ascension pipe to inclined retorts is usually from the lower mouthpiece. It is asserted that the make of tar is somewhat lower than with horizontal retorts, and this points to a greater production of gas. When the retorts are properly heated no accumulation of tar should take place at the lower mouthpiece. The cost of erecting inclined settings is considerably greater than that of erecting settings for horizontal retorts; but comparatively simple charging machinery for sloping retorts enables them to be worked with greatly diminished labour compared with the hand charging of the horizontal variety. The settings occupy less ground space than those for horizontal retorts for the same make of gas. The most palpable disadvantages of the system are the liability of the retorts to drop in the middle, and subsequently to crack, unless the supporting walls are more numerous and substantial than are customary for the same length of horizontal retort, and the need for a very thick front to the setting to withstand the thrust of the retorts. The heat on the charging stages is most oppressive unless the house is very liberally ventilated, and this is still more noticeable when the arrangement mentioned is reversed, and the charging stage is in the middle of the house and serves for the two benches of retorts, which slope downwards towards the walls of the house. Of course further difficulties supervene if the retorts are not at the angle most suitable for the description of coal carbonized.

Mechanical Stokers.—Inclined retorts lend themselves more readily to the use of mechanical appliances for charging and drawing than horizontal, but the latter being, in many minds, superior in other respects, many machine stokers have been invented for them. Of these a few only have survived the ordeal of extended trial under ordinary working conditions. As the tendency at the present time is to free a gas works, as far as possible, from the trammels imposed by the generalissimi of labour cliques, these machines, which diminish the number of workers in the retort house, and do not require the skill or physique of the ordinary gas stoker, must be briefly mentioned. The simplest substitute for the ordinary manual charging, as described above, is perhaps **Wests' Manual Charging Machine**, which consists of a light trolly, which is pushed into the retort to charge it. It is worked in conjunction with a machine for breaking the coal moderately small, and an elevator or conveyor for transferring the broken coal to a hopper, whence it falls, as required, into the charging trolly. Two men only are required to charge retorts by this method, in place of the gang of six required for the ordinary scoop charging of through retorts. It is, therefore, especially adapted for use in small works. The coal-breaking machine, conveyor and hopper, introduced into gas works by John West for stoking machinery, are in slightly different forms adjuncts of nearly all modern systems of mechanically charging retorts. An efficient hand-drawing machine, which permits of the use of a large, wide rake head, is supplied for use in conjunction with the West manual charging machine. The manual charging and drawing machinery, as now made by West's Gas Improvement Co., Ltd., is shown in Fig. 17. West, the inventor of the manual trolly, has given much attention to designing and perfecting retort-charging and drawing machinery, and his plant has probably been more extensively tried than any other. The original designs, and the successive improvements introduced by him are protected under the following patents:—No. 789 of 1881, No. 1,226 of 1886, No. 723 of 1888, No. 5,806 of 1893, and Nos. 5,036 and 5,037 of 1895; for full details, the specifications should be consulted. The compressed air system of conveying power to the machines is that generally recommended by West's Gas Improvement Co. for use in large works, and has been brought by them to a high state of efficiency, productive of great economy. The **drawing apparatus** consists essentially of a rake projected into and withdrawn from the retorts by a bar held in channel guides on the machine. This bar can be raised or depressed by a rocking lever, and so kept above or lowered into the coke at will. The bar is propelled

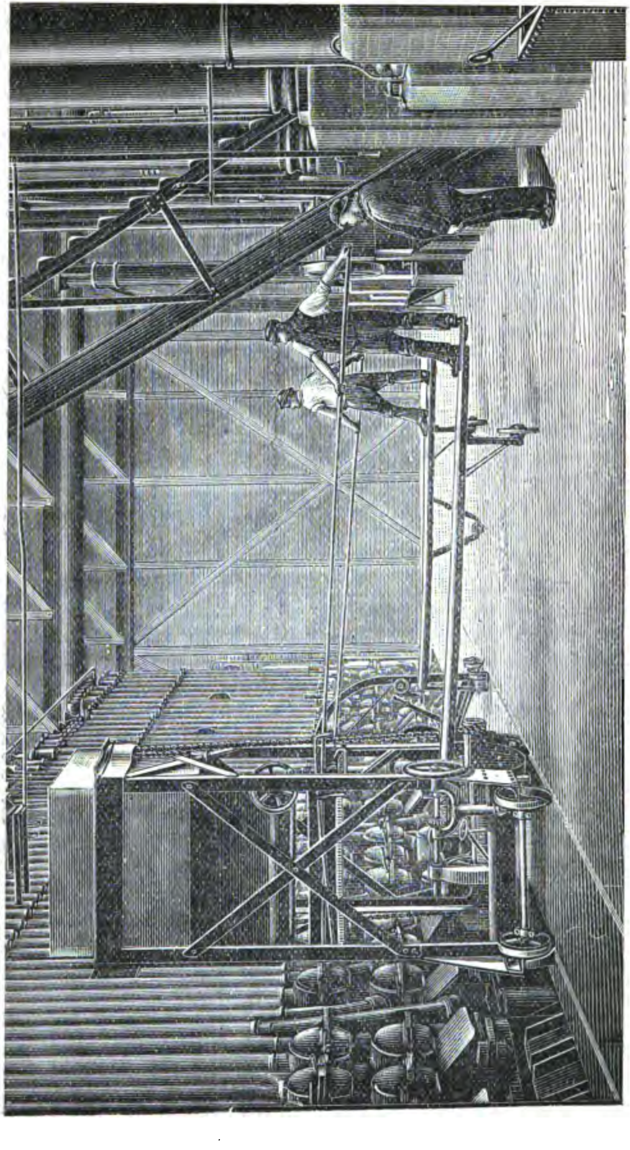

Fig. 17.—West's manual charging and drawing machinery.

forwards and backwards through chains working round a drum connected to the piston-rod, the movements of which are controlled by a hand-lever actuating a slide valve, which admits compressed air to either side of the piston. The rod is cooled each time it is withdrawn from the retort, by a spray of water from a tank carried overhead. A winch worked by a hand-wheel hoists or lowers the frame holding the rake bar to the heights required by the different levels of the retorts. The machine is propelled on rails running the length of the retort house, by means of a hand-wheel actuating bevel gearing connected to one of the supporting wheels, or by means of gearing driven by a compressed air motor. This drawing machine does its work rapidly and well, and, when worked with ordinary care, without injury to the retorts and mouthpieces.

The **charging machine** is likewise supported on rails, and is propelled by a motor, to enable it to travel along the rails in either direction as required. The charge of coal is put into the retort by means of a scoop, which is half the length of a through retort. The scoop is charged from a coal hopper in the upper part of the framework of the machine. The frame supporting the scoop and the hopper can be raised or lowered, according to the level of the retorts, by means of the motor. The scoop is directly supported by a carrier running in horizontal guides, a chain passing to each end of the carrier and then round a drum. The drum is revolved by a pinion operated by a rack attached to the piston-rod of a cylinder, into which compressed air is admitted by movement of a hand-lever. The end of the cylinder to which the air is admitted determines the direction of revolution of the drum and, thereby, the driving forward or backward of the scoop carrier. The scoop is pushed fully into the retort twice to make a complete charge; the first time it enters it is emptied to one side, then withdrawn, refilled, and sent in a second time, when it is emptied to the opposite side to the former charge, and withdrawn; in both operations, the scoop moves several inches from the centre of the retort to the side where the coal is to be deposited. The scoop has a blade running throughout its length to further the even distribution of the charge on the bottom of the retort, and the lateral movement given to the scoop, previous to emptying, has the same object in view. The whole cycle of operations is readily performed by one man, but another must follow the machine to close the retort lids. The hopper attached to the machine is replenished from fixed hoppers placed at intervals above the stage, and filled by elevators. The machine works well, and the average time occupied in charging each retort is forty seconds. The West

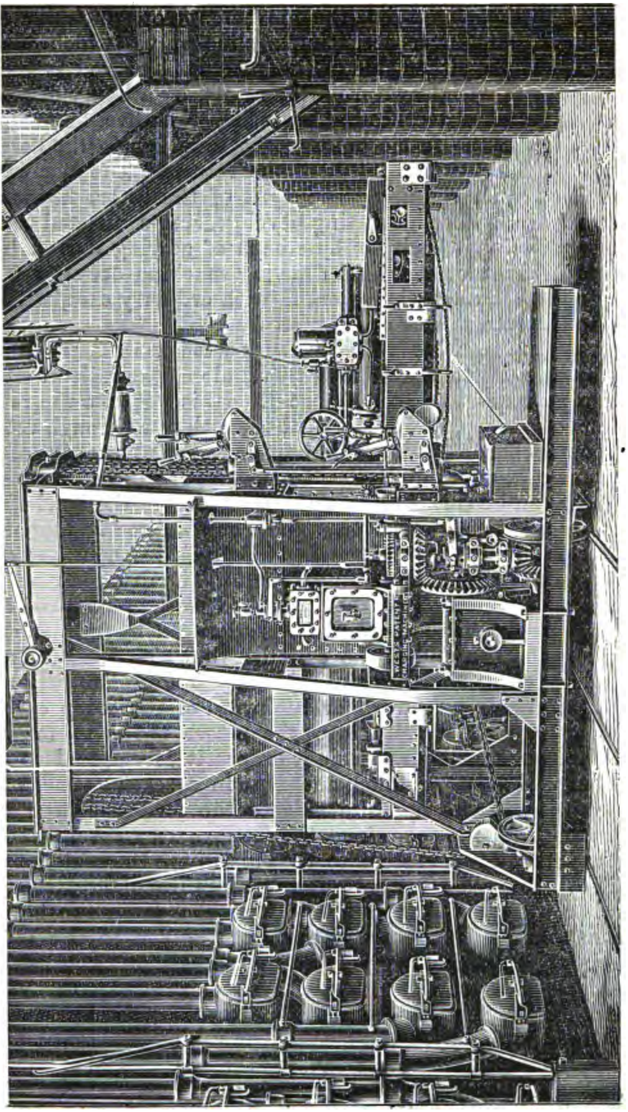

Fig. 18.—West's compressed-air charging machine.

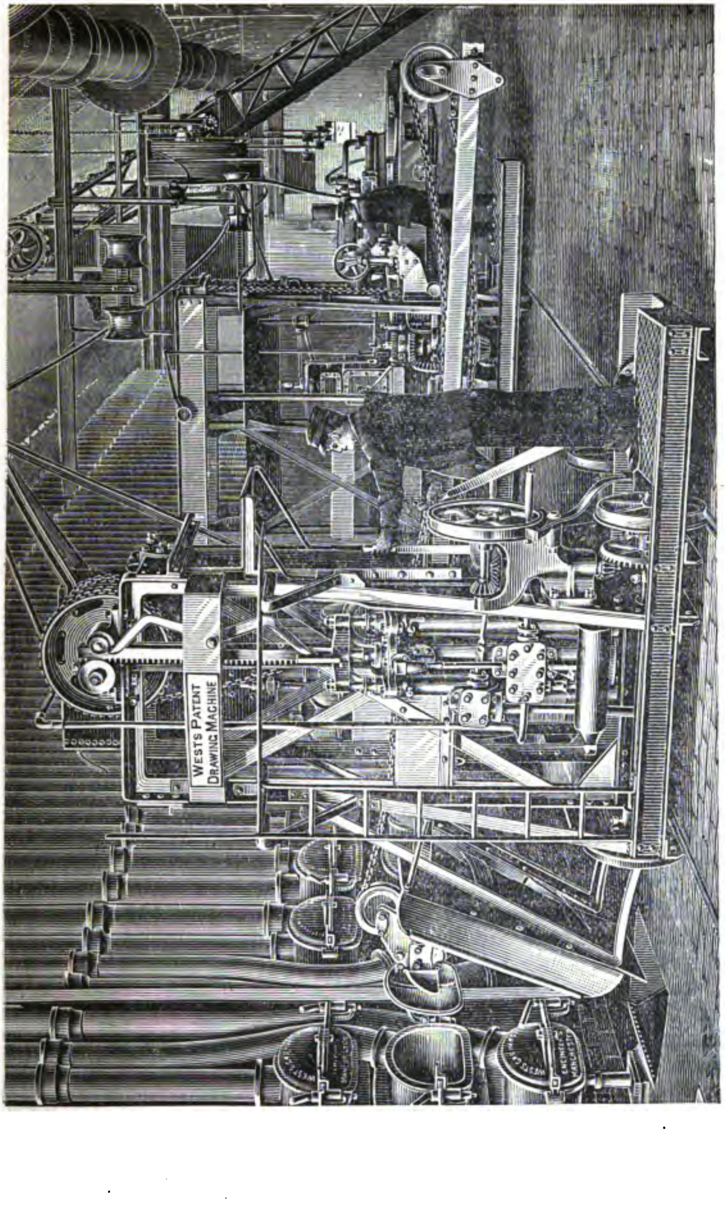

Fig. 19.—West's compressed-air drawing and charging machinery.

machines can also be driven by hydraulic pressure and by wire or cotton rope, and many specimens so driven are at work, but the compressed air system is that generally preferred. Fig. 18 shows the latest form of West's charging machine.

Fig. 19 shows the compressed-air drawing and charging machines, being a view on the stage of the Bradford Road Works at Manchester. The whole of West's charging and drawing machinery is made by West's Gas Improvement Co., Ltd., Manchester.

Ruscoe's charging machine, as at present made, is the result of successive improvements on the inventor's original design, as may be seen from an inspection of patent specifications—No. 18,108 of 1889, No. 14,720 of 1890, No. 8,479 of 1891, and No. 864 of 1892. The charge is put into the retort at one operation, by means of two scoops carried side by side, and overturned in opposite directions. Where desired, the scoops can be drawn slightly apart as soon as they have entered the retort, to their full extent, so that some of the charge is dropped directly on to the middle of the retort floor, and the remainder afterwards distributed to the sides by the tipping of the scoops in the usual manner. The scoops are moved into and out of the retort in somewhat the same manner as that adopted in the West machine. The machine is designed for a charge of 3 cwts. of coal, which it distributes very evenly in the retort.

The **Woodward and Crossley charging machinery** (see patent, No. 4,246, 1892) has a gas engine attached, to provide the requisite power. The machine travels on rails in front of the retorts, gas being supplied to the engine by means of a flexible pipe, or from a water-sealed trough traversing the house. In the latter case the water is taken from the trough for cooling the cylinder, being afterwards returned to it. The scoop is filled from a hopper travelling on the machine, having a shoot the same length as the scoop, thus filling it at once. In a later patent of J. Woodward, two scoops are described of such section that, when overturned in the manner shown, the coal is very evenly distributed in the retort. The machine, of course, contains mechanism for raising and lowering the scoop to suit the heights of the retorts, and can be moved along the rail by gear on one of the axles worked by the gas engine. A gas engine hardly appears at first sight suited for working within the retort house, but these machines have to a great extent dispelled any doubts arising on that head. Nevertheless, it appears that one large gas engine outside the house is likely to be used in place of small ones on the travelling machines, the power being conveyed to the latter by friction pulleys. Woodward and Crossley's patents also cover a design for a drawing machine, which is likewise driven by a gas engine supplied with gas in the same manner as that on the charging machine. The arrangement of the rake is not very dissimilar to that of the West machine, and the supporting rod is likewise cooled by water each time it is withdrawn from the retort. There is considerable similarity in design in most of the machines for discharging the coke at present on the market, and the West may broadly be taken as typical of them all.

The **Foulis-Arrol charging machine** acts in a totally different manner to those previously described. Details of it will be found in patent specifications No. 14,440 of 1891 and No. 16,749 of 1893. The coal is discharged in measured portions, generally one-sixth of the total charge, on to a shoot placed in the mouthpiece, and is then pushed along the bed of the retort by a pusher-head. The first portion is pushed to the end of the (single) retort; the stroke of the pusher diminishes automatically with each successive portion until the retort is fully charged. The amount of coal delivered each time can be regulated to suit the number of strokes made by the pusher. The coal being put in in portions banks up slightly, but appears, nevertheless, to carbonize perfectly. The machine is considerably lighter than most of the power chargers on the market, and can be propelled along the stage by two men. The pusher is driven by hydraulic power, which is also used for raising the charging frame to the upper tiers of retorts. A very light hydraulic power drawing machine has also been designed, and may be used with advantage where hand charging is retained, as well as where the charging machine is used.

An ingenious charging machine has been patented (No. 16,750, 1892) by **F. Grein.** A funnel-shaped tank discharges coal on to an endless metal band traversing a long metal frame which is thrust into the retort. The band distributes the coal on the floor of the retort as the trolly carrying its frame and the coal hopper is drawn backwards from the setting. The trolly either runs on the stage of the house or is supported by a frame running on beams above.

Continuous Carbonizers.—The principal machine stokers have been now enumerated, but before passing on to consider the phenomena of carbonization, brief reference may be made to continuous carbonizers. For years schemes for distilling coal and oil continuously have been propounded, but have not proved workable. The latest and most promising invention of the kind is the **Yeadon & Adgie revolving retort,** which has met with some measure of success. The patent for the original invention is

No. 19,183 of 1889, but various modifications have been since protected. A conical cast-iron retort is set with its axis horizontal, and revolved on suitable bearing rollers. The middle portion of the retort passes through a furnace, which heats it to a bright cherry-red heat. The coal enters at the small end, being carried through a small cylinder by a shaft fitted spirally with blades which make a gas-tight packing to the cylinder. The gas passes out by a fixed ascension pipe at the large end, while the coke drops into a channel from which it is removed by a similar spiral conveyor to that used for supplying the coal. The joints between the stationary and revolving parts are made gas tight with asbestos packing. The carbonization of coal is effected in this retort in less than a quarter of an hour, and a great part of the tar obtained in the ordinary process of gas making appears to be converted in the revolving retort to gas, increasing both the quantity and quality of the latter from a given amount of coal. The coke obtained is small and comparatively valueless. The system seems well worth consideration for use as an auxiliary to ordinary retorts, and generally for intermittent use, but no experiments with it on a large scale have been made, and its general adoption is more than problematical. Nevertheless, its invention shows an appreciation of the direction in which we must look for any considerable improvement in our carbonizing methods, and on this account the Yeadon & Adgie retort must not be ignored. It is adapted with slight modification for the destructive distillation of tar and other hydrocarbon liquids.

Carbonization Products of Coal and Hydrocarbons.—The above brief description of the appliances and mechanical devices used for obtaining gas from coal leads up to the consideration of the most essential conditions governing its production and determining the nature and proportions of its several constituents. The majority of the schemes for producing coal gas are so nearly allied that gas almost identical in composition may be obtained by all of them, and, consequently, we may assume that its evolution is governed by the same general principals, notwithstanding differences in form and working of the apparatus employed in the production. These general principles are less perfectly understood than is commonly supposed.

The elucidation of the phenomena of coal gas manufacture would be far easier were our raw material a less heterogeneous aggregation of carbon compounds. Some light may be thrown on the subject by the close study of the dry distillation at various temperatures of pure hydrocarbons, such as cellulose, and members of the paraffin and other series of carbon compounds. Coal is so complex a body, and its elementary constituents are grouped together in compounds, the natures even of few of which are known, that the ultimate analysis of a sample gives very little indication of its behaviour on carbonization. The rules by which gas is made at the present day are for the most part empirical, and the large profits that the industry yielded ungrudgingly until recent years have tended to repress attempts to establish it on a more scientific basis. Nevertheless, something in this direction has been accomplished, and under the stress due to the competition of other lighting agents much more may be anticipated in the near future.

The carbonization of coal as it takes place in gas works, is conducted under such conditions that the stages in the formation of the permanent gas, which is the chief object of the process, cannot readily be observed. To a limited extent the actions that occur in the gas retort may be deduced on *a priori* grounds, and inferred from analogous cases. Thus, supposing an ordinary horizontal retort heated to 800° C. is ready for charging, and a charge of coal is put in covering the bottom of the retort evenly to a depth of say 3 inches. The temperature of the coal rapidly rises from the normal, the exterior of the layer being first affected. The points of volatilization of the water and the light hydrocarbons of the coal are rapidly reached; in the case of the coal in direct contact with the retort, or fully exposed to the heat radiated from it, almost instantaneously. The vapour of water and of hydrocarbons so expelled seeks the outlet of the retort, but before reaching it, is exposed to the intense radiation from the sides of the retort, even if it does not actually come in contact with them. The nature of the vapour first expelled from the coal must determine the result of the action of heat on it, and as it may vary with the kind of coal, and in any case is not certainly known, we cannot theorize much further in this direction. But since the general tendency of hydrocarbons on exposure to high temperatures in a state of vapour is to break down to carbon compounds of less complex molecular structure, it may be assumed that this happens in the retort, the steam perhaps being decomposed and reacting to a limited extent also. This process of the breaking down of the hydrocarbons as soon as they are liberated in the form of vapour from the coal, doubtless goes on throughout the period of gasification, and is sufficient to explain the presence of the hydrocarbons found in coal gas. At the same time as the retort is imparting heat to the coal the temperature of the former is, in accordance with the theory of exchanges, sensibly lowered. Hence the temperature at which the first part of the distillate is given off is considerably lower than that of the retort before the admission of the charge. But that the distillation temperature may not be below that at which the bulk of the hydrocarbon vapours evolved are converted to simpler bodies which are gaseous at ordinary atmospheric temperature and pressure, a considerable excess of heat must have been imparted to the retort, as fireclay is too feeble a conductor to permit the heat from the furnace to pass through it sufficiently rapidly to compensate for the sudden abstraction of heat by the cold charge. Hence it is the custom to raise the retorts to a temperature considerably above that at which the constituents of coal gas are actually formed from the vapours of the hydrocarbons contained in coal. This is especially necessary where the mass of coal inserted at each operation is large in proportion to the heating surface—*i.e.*, where large charges which form a thick layer in the retort are used. The heating proceeds from the outside of the layer of coal inwards, and gradually causes the volatilization of the hydrocarbons of the coal in the interior of the charge. Moisture in the coal especially tends to lower the temperature of the retort on account of the large amount of heat absorbed in converting it to vapour, or using the common term, on account of the high latent heat of steam. Hence coal for carbonization should contain as little moisture as possible. As soon as the moisture is driven off the temperature rises rapidly, and the heavier hydrocarbons volatilize. But owing to the thickness of the layer of coal usually carbonized, the heat passes to the interior of the mass very slowly, and the process of volatilization extends gradually only. Also, at each moment, hydrocarbons of very different boiling points are given off from different parts of the charge, according to the varying temperatures. Nevertheless all are submitted to nearly the same temperature before they pass from the retort. The amount of heat rendered latent, and the slow passage of the heat through the coal, render the process of gas making under the usual system a slow one, and the charge usually remains in the retort from four to six hours. This prolonged heating is not necessary for the perfect gasification of coal, but is inherent to the system of charging large masses of coal at a time, and to the use of retorts of feebly conducting material. The rapidity with which coal may be carbonized is proved in the working of small experimental iron retorts, and of the revolving gas retort, where the mass in the retort is small enough to favour rapid diffusion of heat throughout it. In these two cases, also, it is not necessary to keep the heat far above that of the conversion of the hydrocarbons of the coal to stable gases, as no sudden and exhaustive call is made on the heating arrangements by the insertion of a large mass of cold solid material at one time. Hence small retorts, and the revolving retort, may advantageously be of iron, which will withstand the heat they require while its good conducting powers are secured. But large retorts holding charges in a layer 3 to 6 or more inches in thickness must necessarily be of a more refractory material.

Little is known of the nature of the constituent hydrocarbons of ordinary gas coal. In certain rich coals hydrocarbons of the paraffin and olefine series are undoubtedly present, and their behaviour under the treatment to which coal is subjected in gas manufacture may be considered with advantage, being doubtless analogous to that of the constituents of ordinary gas coal.

The higher members of the paraffin series of hydrocarbons (C_nH_{2n+2}) break down even at temperatures below their boiling points under normal pressure, to lower hydrocarbons of the same series, and hydrocarbons of the olefine series (C_nH_{2n}). Thus—

$$C_NH_{2N+2} = C_nH_{2n+2} + C_nH_{2n}. \quad \text{Where } 2n = N.$$

Assuming that this action occurs on the application of a high temperature to the lower members as well as the upper, we should find the higher paraffins resolved chiefly into ethane and ethylene. Now at a red heat ethane yields methane, carbon, and hydrogen, thus—

$$C_2H_6 = CH_4 + C + H_2.$$

From paraffin hydrocarbons we should therefore expect to obtain the gases methane, ethylene, and hydrogen, and a deposition of carbon.

The hydrocarbons of the olefine series break up at a red heat to lower members of the same series, to members of the acetylene series, to methane and other paraffins in small quantity. Thus from ethylene are obtained methane, acetylene, and smaller amounts of ethane and other hydrocarbons. Now acetylene at a red heat polymerizes to benzene, and thus a new series of hydrocarbons is introduced. Therefore, from the higher hydrocarbons of the paraffin series are obtained directly or indirectly the following gases, or easily vaporized bodies:—Hydrogen, methane, ethylene, acetylene, and benzene, besides isomers of the last four in small quantities. None of the reactions alluded to above occur completely, but according to the well-known theory of reversible chemical changes, an equilibrium is established at the reacting temperature, and both the original bodies and the products are present in certain proportions dependent on the temperature and pressure in the reacting mixture. Secondary actions occur freely also.

The influence of the oxygenated bodies which are present in coal must also be considered. As a general rule, organic bodies containing oxygen, on heating, decompose, through the splitting off of the oxygen in conjunction with hydrogen as water, or with carbon as the monoxide or dioxide. The hydrocarbon residues unite to form hydrocarbons, which may then undergo a further change according to their nature. This decomposition of oxygenated compounds would suffice to explain the presence of the oxides of carbon among the products of the destructive distillation of coal.

But to account for the presence of certain other products of coal carbonization the secondary actions that take place in the retort must be regarded. We have seen that acetylene readily polymerizes to benzene, and either indirectly or directly this body also is formed at a red heat from the vapours of most methane derivatives. Together with it are formed some of its isomers, also diphenyl, naphthalene, anthracene, phenanthrene, and other products containing either the benzene nucleus or condensed benzene nuclei. Herein lies the explanation of the presence of benzene vapour in coal gas, and of benzene and other aromatic hydrocarbons in the liquid products of the destructive distillation of hydrocarbon bodies. It is a commonly observed fact that the yield of benzene and other aromatic hydrocarbons is greatest when the heat is intense, or its application to the vaporized hydrocarbons prolonged, and this is in accordance with the principle that benzene is formed at a higher temperature than the gaseous methane derivatives, and that it is probably the result of a secondary action. In the formation of aromatic hydrocarbons from paraffins and olefines hydrogen would be liberated, hence the preponderance of that gas in coal gas, especially when the latter is made at a high heat.

It is not pretended that the above reactions completely, or even to any considerable extent, explain the formation of the products of the carbonization of coal, but they offer a partial and possible explanation, and for lack of more definite knowledge may serve to show the general course of the process. When our knowledge of the constituent hydrocarbons of coal is approximately exact, the true transformations occurring during carbonization can be learned from experiments on the effects of different degrees of heat on these hydrocarbons singly and in groups of a few, but at present no such knowledge is available. Hence the inadequacy and defectiveness of the explanations hitherto offered.

Mills' Theory.—Prof. E. J. Mills has attempted to show that in the destructive distillation of coal a very simple relation subsists between the fixed carbon and the carbon in the gas and tar. He concludes that C_3 appears the fundamental unit in all cases, and by using collocations of symbols to represent coal and gas and tar, he gives instances of the concordance of his theory with the results found in practice. Thus excluding the minor constituents, he finds that the organic matter of a coal is nearly represented by the collocation of symbols, $C_{24}H_{18}O$. Its destructive distillation may be thus represented :—

$$\underset{\text{(Coal.)}}{2C_{24}H_{18}O} = \underset{\text{(Fixed carbon.)}}{33C} + \underset{\text{(Gas and tar.)}}{C_{15}H_{34}O} + \underset{\text{(Organic water.)}}{H_2O}$$

According to this, 100 parts of the organic matter of the coal should yield 61·5 parts of carbon, 35·7 parts gas and tar, and 2·8 parts water. In practice 61·5 parts fixed carbon and 38·5 parts volatile matter were actually obtained after eliminating the effect of the minor constituents of the organic matter of the coal by calculation. The results from other coals are given by Prof. Mills, and are in accordance with his theory, which will, however, be generally regarded as too elastic, and is certainly at present incomplete. As an attempt to throw light on the phenomena of destructive distillation it may well find favour, and perhaps furnish a basis for further generalizations.

Distribution of Nitrogen in Distillation Products.—Before studying the influence of temperature on the production of gas from coal, and the composition of the different fractions yielded on the distillation of coal, it may be advantageous to see what becomes of the minor constituents of coal during carbonization. Those of most interest to the gas maker are nitrogen and sulphur. Prof. Wm. Foster studied the distribution of the nitrogen of coal among the several products of destructive distillation.* He concluded that in ordinary gas manufacture, of the total nitrogen in the coal, 14·5 per cent. is evolved as ammonia, 1·56 per cent. as cyanogen, while 48·68 per cent. remains in the coke. There is still 35·26 per cent. as free nitrogen in the gas, or contained in the tar, but the amount in the latter is considered to be relatively small. Apart, however, from basic bodies containing nitrogen which are yielded on the distillation of coal tar, the pitch on cooling evolves a considerable amount of nitrogen, which may be increased by the passage of moist air or steam. According to Watson Smith,† coal tar contains 1·667 per cent. of nitrogen, or a very small proportion of the nitrogen in the coal. Yet some of this nitrogen must be combined in a very stable form, as it remains in the coke from pitch, and is evolved as ammonia during cooling.[*] The coal on which Prof. Foster conducted his experiments contained 1·73 per cent. of nitrogen. Generally the amount of nitrogen in gas coals lies between 1 and 2 per cent. E. Schilling has observed that the amount of ammonia produced rises and falls with the amount of nitrogen in the coal, and he finds that 14·0 per cent. of the total nitrogen is the average yield as ammonia, and 20 per cent. the maximum in a number of experiments.[†] According to Lewis T. Wright,[‡] the yield of ammonia from a coal is greater at a medium than at high or low heats, and he instances this by a typical example of the distillation of a coal from the borders of Yorkshire and Derbyshire containing 1·28 per cent. of nitrogen. At a high heat, when 11,620 cubic feet of gas were made per ton of coal, 0·331 ammonia per cent. of coal was obtained, at a lower heat with a make of 10,162 cubic feet, 0·352 ammonia per cent. of coal, and at a still lower temperature with a make of 9,431 cubic feet, 0·335 ammonia per cent. of coal. Thus the medium heat gave the highest yield of ammonia. It will be observed that these figures show a higher percentage of the nitrogen of the coal as ammonia than was found by Prof. Foster—viz., 22·3, 23·6, and 22·6 respectively, against the 14·5 of the latter. According to G. Beilby, 17 per cent. of the nitrogen in shale is obtained as ammonia on destructive distillation, and some figures given by C. Winkler[§] point to nearly 20 per cent. of the nitrogen of coal being obtainable as ammonia on distilling it in coke ovens. Accurate figures as to the disposition of the nitrogen of coal cannot readily be obtained from the ordinary working on a large scale in a gas works. The percentage of nitrogen recovered as ammonia may be increased in various ways. By the admixture of 2·5 per cent. of lime with the coal before carbonization the production of ammonia is sensibly increased, and further additions of lime up to 10 per cent. cause still further increase in the ammonia produced. The admixture of lime with coal before carbonization under Cooper's process will be considered later; but one of the chief advantages claimed for it is increased yield of ammonia. In one instance where the same description of coal was carbonized with and without lime, the nitrogen recovered as ammonia was 0·19 per cent. of the coal when lime was not used, against 0·27 per cent. when lime was used. The admixture of silica with coal does not appreciably affect the yield of ammonia.

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* *Journ. Chem. Soc.* for February, 1883, p. 105.

† *Journ. Chem. Soc.* for April, 1884.

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[*] Watson Smith, *Journ. Soc. Chem. Ind.*, 1892, p. 119.

[†] *Dingler's polyt. Journ.*, vol. cclxv., p. 218.

[‡] *Journ. Soc. Chem. Ind.*, 1888, p. 59.

[§] *Chemiker Zeitung*, 1884, p. 691.

Were the chief object of the destructive distillation of coal the recovery of as much as possible of its nitrogen as ammonia, several means not adopted in gas works might be resorted to.

For instance, the passage of steam or certain gases over the coal during carbonization increases the yield of ammonia. Hydrogen is specially effective, causing no less than 35 per cent. of the nitrogen in the coal to be evolved as ammonia under favourable conditions. Carbonic oxide slightly improves the yield; coal gas appears to hinder the formation of ammonia through deposition of finely-divided carbon on the hot material.* The temperature at which ammonia is decomposed is below that at which carbon decomposes steam, consequently we do not find a large yield of ammonia from water-gas generators, although hydrogen is present in the upper part of the fuel bed. Ramsay states that ammonia may, under favourable conditions, decompose under 500° C., hence its dilution with a large volume of neutral gas suggests itself as a means of preserving it during its passage through the retorts. This probably explains the action of steam in increasing the yield of ammonia. Either alone or admixed with air, steam passed over coal at an ordinary carbonising temperature, or, more certainly, at a somewhat lower heat, will convert 60 per cent. of the nitrogen of the coal into ammonia.† As ammoniacal liquor is generally worked up into ammonium sulphate—a readily marketable product—the yield of ammonia from coal is often stated in its equivalent amount of ammonium sulphate per ton of coal. This can readily be approximately converted into percentage of nitrogen in the coal by means of the following factor :—105 lbs. ammonium sulphate (pure) per ton of coal is equivalent to 1 per cent. of nitrogen in the coal.

Distribution of Sulphur in Distillation Products.—The behaviour of the sulphur contained in coal, when the latter is submitted to destructive distillation, may now be considered. The methods of estimating sulphur in coal have been given in Chapter i., and it must have been apparent from the information given there that the form in which the sulphur is combined, influences the amount and nature of the sulphur compounds it yields to gas. The sulphur present in coal as sulphate, generally of calcium, remains as such in the coke remaining on destructive distillation, and its amount may be estimated in the ash. The remainder of the sulphur exists in the coal either as organic sulphur compounds or as pyrites. The roasting of these in a reducing atmosphere gives rise chiefly to hydrogen sulphide, but also to carbon disulphide. The latter compound was originally discovered by its formation when pyrites and charcoal were heated together, conditions almost analogous to those obtaining when pyritic coal is being carbonized. Small amounts of other sulphur compounds also pass into the gas. Some of the volatile sulphur is condensed in the tarry products, but this is probably only a small percentage of the whole. No exhaustive experiments on the behaviour of the sulphur of coal during destructive distillation have yet been carried out, and further information on the subject is much needed. Difficulties arise at the outset of an investigation of the matter, owing to the difficulty of differentiating between the sulphur combined organically, and as pyrites in the coal. It appears from experiments conducted by I. S. Drown,* that the whole of the iron present in coal does not exist as pyrites. However, both the organic and pyritic sulphur are partly eliminated in the gas, though some of the former almost invariably remains in the coke, and appears in the products of combustion of the latter. The exact distribution of the organic and pyritic sulphur of coal among the gas, tar, and the coke has not been satisfactorily determined for given samples. The general experience is that the destructive distillation of good caking coal produces gas containing about 1·6 per cent. of its volume of sulphuretted hydrogen, and, in addition, about 0·03 per cent. by volume of carbon disulphide and other vaporized sulphur compounds. From experiments I found that the crude gas, taken from the hydraulic main, contained, on an average, 1·2 per cent. of its volume of sulphuretted hydrogen, when coal containing 1·1 per cent. of sulphur was being carbonized.

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* See a paper by R. Tervet, *Journ. Soc. Chem. Ind.*, 1883, p. 445.

† See a paper by George Beilby, *Journ. Soc. Chem. Ind.*, 1884, p. 216.

The proportion of the total amount of sulphur in the coal which passes into the gas on carbonization, increases with the temperature of distillation, especially that portion which is not evolved as sulphuretted hydrogen. This even increases at a greater rate than the volume of gas made, so that high heats mean not only a greater amount of sulphur in the total gas from a given weight of coal, but even a greater amount per volume of gas made. For the results of a number of experiments on this point, a paper entitled "Studies in Coal Distillation," by Lewis T. Wright, may be consulted.† The admixture of a small amount of lime with the coal, prior to distillation, diminishes the quantity of sulphur passing into the gas; in some cases, by as much as one-half its weight under the ordinary conditions.

Quality and Quantity of Gas Produced.—The carbonization of coal may now be considered in relation to the quality and quantity of gas produced. The gas evolved shortly after coal is placed in a retort at an ordinary carbonizing temperature, contains the gases occluded in the coal. These are mainly nitrogen and methane, with small quantities of oxygen, carbonic acid, and other gases; consequently, the illuminating power of the gas coming from the retort during the first half hour after charging is very low. Then it rises rapidly, and the gas evolved during the next hour is the best obtained from the charge. If the heat of the retort is low, this period is prolonged, and the gas is even richer. But, from the middle or end of the second hour to the end of the third hour, it may be taken that the gas will be considerably poorer, and thence to the end of the distillation that it will be very poor indeed. The period at which the richest gas is produced is also that of the most rapid production, though the rate of evolution does not fall off markedly in the ensuing period.

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* *American Chem. Journ.*, vol. iv., p. 1.

† *Journ. Soc. Chem. Ind.*, 1888, p. 59.

In the manufacture of gas from ordinary good gas coal, when about 11,000 cubic feet of gas, having an average illuminating power of about 14 standard candles, is made, the fraction produced during the first half hour, amounting to about a seventh of the total volume, will be only about 10 candle gas. During the next hour and a-half, the candle power of the gas made will be 17 to 18, and the production nearly one-half of the total. During the next hour, the make will be nearly a fifth of the total, but the candle power only about 14. The remainder of the gas will be only 8 to 10 candle. These figures are, of course, only rough approximations, and the description of coal, the heat, and the pressure in the retort, may cause great variations from them. They are applicable only to a high heat, and consequent rapid working off of the charge.

The temperature of retorts in gas works is seldom determined with accuracy. For ordinary working, the eye is relied on to determine if the retorts are sufficiently hot, and experience in observation renders it a very reliable guide. The condition of the coke at the time of drawing also serves as an indicator of the temperature, as, if this is low, the charge will not be completely burnt off in the allotted time. Gas engineers are not unanimous in opinion as to the most economical carbonizing temperature, and, doubtless, a decision is liable to considerable modification if the local conditions are in any way altered. It is the custom, however, in most large gas works in this country, to work at a heat which gives a yield of about 11,000 cubic feet of gas per ton of coal, allowing six hours for the working off of each charge. This is generally termed a bright cherry-red heat, and represents a temperature of about 1,100° C. The actual temperature at which the distillation takes place is, however, lower than this, being about 800° C., but before the charge is completely burnt off, it is raised to the higher temperature, or in some works even still higher.

The product of the volume of gas per ton of coal and its illuminating power tend to increase with the first factor, hence high heats, which mean large volume, are apparently more economical. But where gas of a certain fixed illuminating power above that of common coal gas has to be supplied, the economy of very high heats is nullified by the increased cost of enriching the poor gas so obtained. The shortened life of retorts and increased cost of firing also tell against the adoption of very high heats, and most works are content to carbonize at the temperature given above. Where enriching material is expensive, it pays to work at still lower temperatures, and so obtain a better gas at the expense of quantity. Except in very exceptional instances, the economy of working to a make of less than 10,000 feet per ton of good caking gas coal is more than questionable. The quantity and quality of gas from a given weight of coal, though mainly determined by the temperature of distillation, are also affected by the pressure within the retort. This is controlled by the exhauster, and is usually gauged by the pressure in the hydraulic main. This is generally maintained slightly below that of the atmosphere, the difference being represented by the pressure exerted by a column of water from 0·5 to 1·0 inch in height. Where rich gas is required, however, the pressure in the hydraulic main is that of the atmosphere. The effect of increasing the pressure on coal during its destructive distillation is to diminish the volume of the gas evolved, while enhancing its quality. Where the pressure in the retorts is equal to, or above, the atmospheric, gas escapes at cracks and imperfect joints. On the other hand, a considerable vacuum within the retorts is accompanied by the ingress of appreciable quantities of air, unless the retorts are quite sound, and the lids hermetically sealed. The loss of gas in the one case, and the admission of air in the other, account to some extent for the differences in the quality and quantity of gas obtained when the pressure at which it is evolved is different, but the increased production of tar when the pressure is increased shows that the products of the distillation are directly affected.

Retort Carbon.—A curious phenomenon of the destructive distillation of coal is the deposition of carbon on the sides of the retort. The breaking down of hydrocarbon vapours with the liberation of hydrogen, and hydrocarbons containing fewer carbon atoms to the molecule is accompanied by liberation of carbon, and as this process is favoured by a high temperature, the deposit of carbon in retorts might be expected to be greatest where high heats are used. As a matter of fact, this is *cæteris paribus*, found to be the case in gas works. Where a slight vacuum is maintained in the retorts, the gas is removed from them very quickly after its evolution, and in such cases few hydrocarbon vapours are completely broken up, and the deposition of carbon is slight. A pressure within the retorts above that of the atmosphere favours the deposition of carbon. The deposit is very hard and close in texture, and is removed with difficulty. It is generally allowed to accumulate until it forms a layer from 1 to 2 inches in thickness, when it is chipped off with a chisel. The thick layer diminishes the capacity of the retort, and hinders the rapid transference of heat to the charge. In large works, with the retorts in continuous work, the carbon deposit or scurf is removed at intervals of about six months. Some methods designed to supersede the old method of removing the carbon with chisel bars have been proposed, but have not found general acceptance. The retort carbon is a marketable article (see Chapter xi.).

Composition of Crude Coal Gas.—The composition of crude coal gas may be roughly indicated with advantage at this point. As it leaves the dip pipes it contains a quantity of tarry matter in suspension, some of which is deposited in the hydraulic main, and the remainder in the condenser and the purifying plant. The bulk of the gas is hydrogen and methane, but it also contains carbon monoxide, nitrogen, carbon dioxide, hydrogen sulphide, a variable amount of gaseous hydrocarbons, ammonia, and certain other nitrogen and sulphur compounds. Of these hydrogen, methane, carbon monoxide, and the hydrocarbons are desirable constituents, while it is impossible to remove the nitrogen. The other constituents are either completely removed or appreciably diminished in amount by the processes to which the gas is subsequently subjected. The hydrocarbons are also affected by the subsequent treatment. The gas leaves the hydraulic main at a temperature of 50° to 60° C., and enters the condenser at a slightly lower temperature. If the latter is efficient, it should leave it at about 15·5° C., or, at least, very little above the atmospheric temperature in hot weather. Its constitution is somewhat altered by condensation. Aqueous vapour is condensed until the gas leaves the condenser with only the normal saturation quantity for its temperature. Tarry vapours also are condensed, and carry down with them small quantities of lighter hydrocarbons, which would otherwise remain in the gas at the normal temperature. This washing out and solution of some of the illuminating hydrocarbons of gas by the tar is especially prevalent when the condensation is rapidly effected. The aqueous vapour in condensing carries with it some of the ammonia, carbonic acid, and sulphuretted hydrogen of the crude gas, but the ammonia is in excess of the amount required to neutralize the acid radicles, as far as the liquor condensed in the hydraulic main is concerned, while the acids are in excess in the liquor thrown down in the condensers. It is, therefore, evident that the gas at the outlet of the condenser is somewhat altered in composition from what it was on entering the hydraulic main. It has lost a considerable quantity of aqueous vapour and of heavy tarry hydrocarbons, also small quantities of light hydrocarbons, ammonia, hydrogen sulphide, carbon dioxide, and very small amounts of other matters. The percentage by volume of the various constituents of gas from ordinary gas coal, as it leaves the condensers, will lie between the figures given below :—

COMPOSITION OF GAS FROM COMMON COAL AFTER CONDENSATION, BUT PRIOR TO WASHING.

Hydrogen,	from	42	to	53	per cent. by volume.
Methane,	,,	32	,,	39	,, ,,
Carbon monoxide,	,,	3	,,	9	,, ,,
Hydrocarbons—					
Gaseous,	,,	2·5	,,	4·5	,, ,,
Light, condensable vapours,	,,	0·5	,,	1·2	,, ,,
Carbon dioxide,	,,	1·1	,,	1·8	,, ,,
Nitrogen,	,,	1·0	,,	5·0	,, ,,
Hydrogen sulphide,	,,	1·2	,,	2·0	,, ,,
Ammonia,	,,	0·5	,,	0·9	,, ,,
Cyanogen,	,,	0·07	,,	0·12	,, ,,
Carbon disulphide,	,,	0·025	,,	0·035	,, ,,

The gas also contains very small amounts of sulphur compounds not enumerated above, the nature of which is somewhat doubtful; some heavy tarry vapours, amounting, when condensed, to from 2 to 4 lbs. per 1,000 cubic feet of gas, and frequently a small quantity of oxygen. It is, moreover, saturated with aqueous vapour. Some of the minor constituents enumerated above do not exist in the gas as such, but are, partially at least, in combination. For most purposes it is not misleading to regard them as free. The light condensable hydrocarbon vapours are such as are removed by alcohol according to Bunsen's method,* or by exposure to low temperature according to Clare-Deville's method,† and consist almost entirely of benzene and small quantities of its homologues. The nature of the gaseous hydrocarbons will be considered later.

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* Bunsen, *Gasometrische Methoden*, p. 144.

† *Journal des Usines à Gaz*, 1889, p. 13.

The hydrogen will approach the highest figure given for it, when high heats and low pressure prevail in the retorts. The methane is more constant, high heats slightly diminishing its quantity. Carbonic oxide varies somewhat unaccountably; probable the amount of moisture in the coal affects its formation. The gaseous hydrocarbons are highest with low heats, while vapours of aromatic hydrocarbons result more freely from high heats. The amount of hydrocarbons depends primarily on the nature of the coal, but their character chiefly on the heat and pressure in the retort. At the outlet of the condensers ordinary coal gas contains about 1·25 per cent. of carbonic acid. When the nitrogen exceeds 3 per cent. leakage may be suspected. The sulphuretted hydrogen, other sulphur compounds, ammonia, and cyanogen are chiefly dependent in quantity on the proportion of their elements in the coal carbonized. Tar is formed more freely at low heats, but the quantity in the gas at the outlet of the condenser should not be greatly affected by the heat of the retorts.

In gas from cannel, there are larger percentages of methane and hydrocarbons than in coal gas, and the hydrogen is proportionately less. Thus cannel gas contains 40 to 47 per cent. of methane, 35 to 43 per cent. of hydrogen, and from 9 to 15 per cent. total hydrocarbons, of which there is an appreciable diminution by the process of purification of the gas. The remaining constituents are present in very similar proportions to those in which they occur in common coal gas, though in recent years the bad quality of the bulk of the cannel on the market has caused sulphur impurities to be in general higher than in gas from ordinary bituminous coal. The quality of cannel gas is affected in the same manner by the heat and pressure at which the cannel is distilled as that of gas from common coal, and need not be separately discussed. Cannel gives an increasing value for the product of volume of gas and illuminating power, as the volume increases, consequently high heats are generally favoured in producing cannel gas. The coke from cannel is in general in small pieces, and being heavily loaded with ash, is of very little value. The tar from cannel contains a larger amount of "paraffins," or non-aromatic hydrocarbons, than common coal tar, and does not yield pure products so readily in the hands of the tar distiller.

CHAPTER III.

COAL GAS—(*Continued.*)

Impurities in Gas.—Those constituents of crude coal gas which are harmful to it either by reason of their presence having a deleterious effect on the illuminating power, or by reason of the products of their combustion being noxious, are conveniently classed together as impurities. Those of the first order, which the gas engineer prefers, on the score of economy, not to have present in the gas distributed, since they lower its illuminating power in a marked degree, are carbon dioxide and nitrogen. Of these the first, very commonly known as carbonic acid, is the most harmful, and is present in the crude gas as a direct product of the destructive distillation of coal. The nitrogen, less harmful, is in part derived from the breaking up of the nitrogenous constituents of the coal, in part from the air occluded in the coal, and in part from air which has diffused through the retorts or has gained admission through cracks and imperfect joints in the apparatus. There is usually no attempt made to diminish the amount of carbonic acid formed in the process of carbonization; the amount of nitrogen in the crude gas is kept as low as possible by the use of sound retorts and apparatus, and by the maintenance of a pressure slightly higher than the atmospheric within them. The removal of nitrogen from gas is impracticable, consequently nothing further can be done to diminish the amount present. The removal of carbonic acid is comparatively easy, and is more or less perfectly carried out in all works. The chief noxious constituents of crude coal gas are ammonia, hydrogen sulphide, and carbon disulphide. Other nitrogen and sulphur compounds are present in small amount, but do not generally form the subject of any special treatment of the gas. Ammonia, derived from the nitrogenous constituents of the coal, is removed from the gas on account of its marketable value, even where legislative enactments do not render its presence in more than a small (practically negligible) amount a penal offence. Hydrogen sulphide, or sulphuretted hydrogen, formed from the sulphurous constituents of the coal, is almost universally completely removed from gas before its distribution to consumers. This complete removal of sulphuretted hydrogen is generally demanded by law even where no other restrictions as to purity are imposed on the gas works. Carbon disulphide, likewise a direct product of the destructive distillation of sulphurous coal is partially removed from gas in most works, the regulations imposed on gas companies generally limiting the amount of sulphur that may be present in the gas as carbon disulphide and sulphur compounds other than sulphuretted hydrogen to a certain small quantity. Mechanically carried forward with the gas there is also some tar which has escaped condensation in the condensers, and a small quantity of cyanogen, free and combined, may also require consideration.

The process of removing these impurities varies according to the approximation to perfection demanded of it, but the comprehensive scheme carried out where the highest degree of purification is enforced on the manufacturer—as in London—covers all essential points of the partial purification methods, and need alone be given detailed consideration here. It does not involve the removal of each impurity in strict sequence by a separate process, for fortunately some of the impurities aid the removal of others. Thus ammonia is a strong base, while carbonic acid, sulphuretted hydrogen, and cyanogen are of an acid nature. Hence ammonia removed from gas will serve to take up one or more of the acid bodies until it is fully saturated.

The amounts of the impurities in the gas as it leaves the condensers will, with Durham coal worked at a moderately high heat, be about as follows:—

						Grains per 100 cubic feet.		
Ammonia, . . .	0·65	to	0·95	°/₀	by vol.	or 200	to	300
Carbonic acid, . . .	1·2	,,	1·8	,,	,,	980	,,	1470
Sulphuretted hydrogen, .	0·9	,,	1·5	,,	,,	570	,,	950
Carbon disulphide, . .	0·020	,,	0·035	,,	,,	28	,,	50
Other sulphur compounds,	...		...			5	,,	8
Cyanogen, ...	0·05	,,	0·10	,,	,,	50	,,	100

GAS PURIFICATION.

Washing or Scrubbing the Gas.—The first stage in the removal of gaseous impurities is invariably the washing or scrubbing of the gas with water, or, in practice, with the liquors condensed in the hydraulic main and condenser. These liquors, though containing ammonia, sulphuretted hydrogen, and carbonic acid, are not fully saturated, and are capable of absorbing much more of each of these impurities. With them is generally mixed the liquor or washing-water of the last stage of the washing process, which likewise contains a small quantity of each of these impurities. It is desirable to perform the whole of the washing of the gas with as small a bulk of water as possible, so that the resultant liquor may contain a high percentage of ammonia, and that the subsequent recovery of the latter may be rendered as economical a process as possible, through the avoidance of handling a large quantity of water per unit of ammonia. The ammonia taken up by the liquor enters into combination with the carbonic acid and the sulphuretted hydrogen in varying proportions, and also with the cyanogen absorbed, so that the liquor will contain both the acid and neutral carbonates, the acid and neutral sulphides, thiocarbonate, cyanide, thiocyanate, and ferrocyanide. The liquor generally also contains sulphate, thiosulphate, sulphite, chloride, and traces of acetate. Many of these salts are, however, present in only small quantities, and the most important factors in the composition of gas liquor to the gas engineer are the quantities of carbonic acid and sulphuretted hydrogen combined in it, and their proportion to the quantity of ammonia present. As neither acid radicle exists in the liquor combined in only one proportion with the ammonia, there is no precise theoretical limit (the maximum theoretical limit, where the whole of the carbonic acid or sulphuretted hydrogen would be present as the acid ammonium salt, is never approached) to the amount of carbonic acid and sulphuretted hydrogen which a given quantity of ammonia in the liquor can absorb, but in practice it is found that the saturated liquor from washer-scrubbers contains somewhat more of the acid radicles than would suffice to form the neutral salts with the ammonia with which they are combined. One combining equivalent of ammonia may be expected to absorb carbonic acid or sulphuretted hydrogen to the extent of $1\frac{1}{6}$ to $1\frac{1}{4}$ combining equivalent of one or both of these acid bodies. In other words, ammonia will take up sufficient sulphuretted hydrogen and carbonic acid to be wholly converted to the neutral salts, and will then continue to absorb them, until at least one-sixth of the amounts absorbed to form the neutral salts has been in addition absorbed. The absorption would, doubtless, continue further, but the practice of gas works is to remove the liquor from further contact with the gas at this stage. The approximate amount of work done by the ammonia of the gas towards the removal of the acid impurities is now evident. The most important consideration is to effect the removal of the ammonia by means of as small a volume of water as possible, and at an expenditure of as little power as practicable. Towards these ends, innumerable mechanical devices have been brought forward, but space is not available for their detailed description.

Tar Extractors.—To prevent the clogging of the scrubbers proper with tar that has escaped deposition in the condenser, the gas is very commonly passed through a small scrubbing apparatus, known as a tar extractor, before it enters those vessels. The principle involved in this apparatus is the subjecting of the gas to friction by causing it to pass through a large number of small perforations in metal plates, which are arranged to cause more or less resistance to the direct passage of the gas, according to the quantity of tar to be removed, and the ideas of the inventor. In some designs, the number of perforations presented to the gas is regulated automatically by the quantity of gas passing into the apparatus in a given time, so that the scrubbing effect of the plant is the same whatever the rate of flow (within fixed, but tolerably wide, limits) of the gas. One of the most popular tar extractors in this country is that of which the patent is held by C. & W. Walker, and on the Continent Pelouze and Audouin's invention has been extensively adopted. The tar extractor separates some ammoniacal liquor as well as tar from the gas. An efficient tar extractor reduces the amount of tar passing forward with the gas to an inappreciable quantity, and saves clogging in the scrubbers.

Tower Scrubbers.—Gas engineers are by no means unanimous as to the best washer and scrubber to be used. The tall tower scrubbers, packed with coke or wooden chequer work down which water or weak liquor trickled and met the gas passing up the spaces left by the packing material, form a prominent feature in most old gas works, but are now generally discarded in favour of the more compact "washer-scrubbers," of which there are several efficient varieties on the market. In the tower scrubbers the water or weak liquor is generally distributed on to the upper layer of coke, or other filling material, by a revolving distributor driven mechanically. Two at least of these scrubbers must be used in series, the one up which the gas first passes being fed with the weak liquor from the hydraulic main, condenser, and last scrubber. The ammonia already taken up in the weak liquor is, therefore, able to take out carbonic acid and sulphuretted hydrogen from the gas, while a further quantity of ammonia is absorbed. The second scrubber, when two only are worked in series, is fed with clean water, and must reduce the amount of ammonia in the gas to within the prescribed limits. The efficiency of tower scrubbers depends on their height, or more correctly, on the sum of the heights of the scrubbers worked in series, and also on the extent to which the gas is split up in its passage through the vessels, and the regular distribution of the water throughout the filling material. Unless the gas is thoroughly freed from tar coke-filled scrubbers choke readily, and the gas passes up by a few large channels only. Washers are very generally used before the old type of scrubbers. In them the gas is passed in finely-divided streams through a number of water seals. The friction and contact with the water remove tar and a quantity of ammonia. They are not generally filled with clean water, but with the overflow liquor from the scrubbers. The depth of water seal varies, but the simple washer should never throw more than 3 inches water pressure. The washer was often placed at the bottom of the tower scrubber, and the gas passed out of it direct into the latter piece of apparatus. The old types of washers were accused of greatly deteriorating the illuminating power of the gas passing through them, and doubtless in the winter months the accusation was often well founded.

The "Standard" Washer-Scrubber.—Of the modern washer-scrubbers, the "Standard," made by Kirkham, Hulett & Chandler, is one of the best known and most efficient, and may be described as typical. It is shown in Fig. 20, in end elevation in B, and in side elevation and part section in A. C and C′ are the gas inlet and outlet pipes. The spur wheel, D, on the shaft, E, is revolved slowly by an engine, thereby causing the bundles (F) of wood and metal attached to the shaft to be carried round with it. The bundles in the lower segment of their circular course pass through the water or weak liquor in the bottom of the washer, and rise up thoroughly wetted by it. By the careful packing of the apparatus the only passage for the gas through it is from the central passage outwards through the interstices in the wetted bundles, and back towards the central line through the narrower open space shown in each segment of the washer. The gas takes a similar course through each section, and is, therefore, brought into very thorough contact with the wetted surfaces. The weak liquor or water with which the apparatus is fed passes through it in the opposite direction to the gas, thus becoming stronger as it meets the cruder gas. The level of the liquor naturally falls in the sections as it passes from one to the other. From the last section it siphons out and is led to the liquor tank. In the liquor overflow there is often placed a hydrometer covered by a bell glass, so that the strength of the liquor passed away may be read off approximately at any time. This washer requires little power to drive it, and throws little pressure in comparison with the amount of work it performs. The bundles do not clog if the tar extractor is working properly. A special patented pattern of wooden bundles is now used by Kirkham, Hulett & Chandler in place of the older iron or composite bundles. Two of these Standard washers working in series, the last being fed

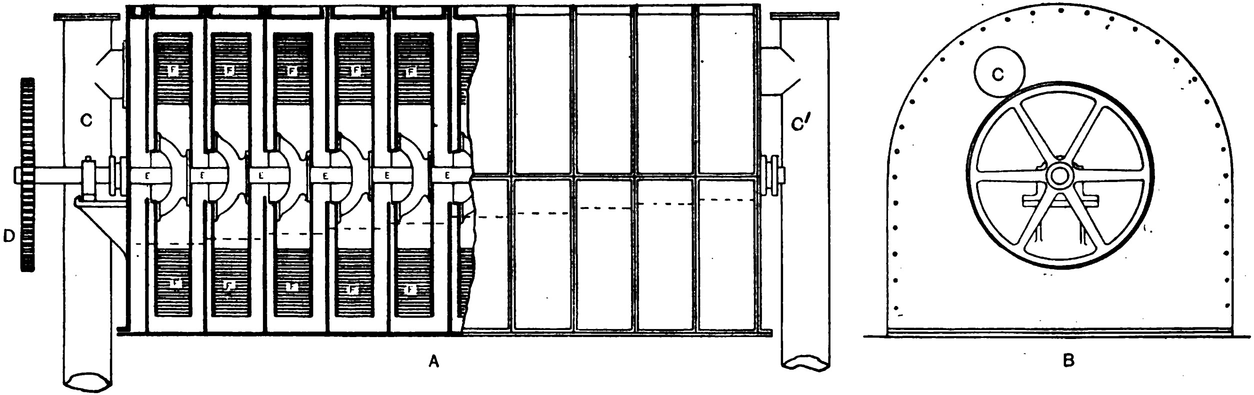

Fig. 20.—" Standard " gas washer-scrubber.

B, End elevation ; A, side elevation and part section ; C, gas inlet pipe ; C′, gas outlet pipe ; D, spur wheel ; E, shaft ; F, bundles.

with clean water, suffice to practically free gas from ammonia. They are made in various sizes according to the amount of gas passing per hour. Roughly, each cubic foot content of the "Standard" washer-scrubber is as effective for the removal of ammonia as 20 cubic feet in the old tower scrubbers, consequently the scrubbing apparatus on a gas works is now far more compact than formerly. Scrubbers working on nearly the same lines are in almost universal use in this country and on the Continent.

Removal of Carbonic Acid.—The gas after passing the scrubbers is, or should be, quite free from ammonia, as indicated by the most delicate turmeric paper, and contains about 500 to 800 grains of sulphuretted hydrogen, and 700 to 1,100 grains of carbonic acid per 100 cubic feet. It also contains about 30 to 45 grains of sulphur compounds other than sulphuretted hydrogen per 100 cubic feet, and, unless special materials have been used for washing as well as gas liquor and clean water, also some cyanogen compounds. These impurities are removed, or diminished in quantity, by means of materials in the solid state in most gas works, though schemes have been propounded for the complete purification of gas by washing with solutions of various substances. These schemes may be dismissed for the present as outside the ordinary routine of gas-works purification. The carbonic acid is the first impurity to be completely removed from the gas, after the scrubbing process, in works where no restrictions are imposed to prevent the adoption of the most economical scheme of gas purification. The reagent invariably employed for the removal of carbonic acid is slaked lime. Lime also removes sulphuretted hydrogen, but it is not economical to use it for the purpose, as the sulphur is not readily recoverable. The materials actually in use at the present day for the removal of sulphuretted hydrogen from gas are hydrated ferric oxide and Weldon mud, the active constituent of the latter being the manganese dioxide. The material by which carbon disulphide is removed or reduced in amount is a compound of lime prepared by acting on hydrated lime with gas containing sulphuretted hydrogen. This material is prepared *in situ* from lime, consequently the only raw materials used in purification which we need consider are lime, ferric oxide, and manganese dioxide.

Mode of preparing and using Lime.—Lime in its fresh caustic state should consist wholly of oxide of calcium (CaO). It is prepared by heating limestone or chalk to a red heat in an atmosphere renewed as frequently as possible, since the carbonic acid evolved by the decomposition of the limestone hinders further decomposition if it remains in the kiln or burning chamber. In some gas works the lime is burnt in kilns fed continuously at the top with a mixture of 2 to 3 volumes of limestone and 1 volume of coke. The product is drawn off at short intervals from the bottom of the kiln, which is thus kept in continuous work. The size of the kiln and the rate of feed are such that the material takes from two to three days in passing through the kiln. Much of the ash of the fuel cannot be removed from the lime produced, consequently the coke must be as free from ash as possible, but, on the other hand, must be slow burning, or it will be consumed before the chalk has been thoroughly converted to lime. In this connection it is necessary to recall the fact that silica and alumina combine with lime to form di- and tri-calcium silicates and aluminates, and if the temperature of the kiln is at all high, the silica and alumina of the coke ash will unite with lime to form the tolerably stable tri-calcium compounds. Hence the silica and alumina of the ash must be considered to render 2·8 and 1·65 times their respective weights of lime inert, as their compounds with calcium are not decomposed on slaking. It is evident, therefore, that the presence of the coke ash not only entails the cumbering of the lime with the weight of the ash, but also the rendering valueless of a considerable quantity of the lime itself. Doubtless some of the clinker and inert material can readily be removed from the lime by hand picking, but the importance of using a coke of low content of ash for lime burning cannot be over estimated if economy is to be attained. To the deleterious effect of ash is to be traced the immense superiority of lime made from limestone or chalk by the aid of gaseous fuel. If ordinary kiln lime is used for purification, care should be taken to see that it is not loaded with siliceous compounds; with flare lime the quality is only affected by the quality of the limestone from which it is burnt, and the degree of perfection of the burning.

A cubic yard of good kiln lime weighs about 11 cwts. Slaking on the large scale, to the degree of moistness suited to gas purification, requires about 135 gallons of water per cubic yard of unslaked lime, and nearly 2¼ yards of slaked lime are formed from each yard of the unslaked material. A yard of lime slaked with the above-quoted amount of water weighs about 11 cwts. Owing to the expansion and heating of quicklime on access of moisture, its storage is attended with some risk. On a gas works the lime is usually slaked in bulk as soon as possible after burning, but it should not even then be stored for any length of time before use, as it rapidly deteriorates in quality by absorbing carbonic acid from the air. When it becomes necessary to store lime after slaking, it should be piled in large heaps, presenting as small a surface as possible. The lime will not then greatly deteriorate on keeping, except for some 12 inches below the surface of the heap.

The spent lime from the vessels in which the carbonic acid is removed from gas consists chiefly of calcium carbonate, and is sometimes reburnt to lime on the gas works. This reburning of spent lime is economical only where new lime is somewhat costly, as the spent material is with more difficulty converted to lime than the natural chalks. The difficulty of reburning spent lime lies partly in the large amount of moisture it contains, and partly in the presence of calcium salts other than the carbonate, especially the sulphate. Hence, where chalk is plentiful and fresh lime can be made at a cheap rate, the reburning of lime will hardly be undertaken; but at works situated far from good chalk supplies it should certainly be adopted. Reburning is always carried out by the aid of gaseous fuel. The waste heat from the burning chambers is generally utilized to drive off the greater part of the moisture from the lime. Only two systems for reburning spent lime have been extensively used. The oldest is Hislop's patent process, by which the gas from a producer is used to heat several small kilns set in one bench. The upper part of the bench is used as a drying chamber, and the spent lime remains in it about eight hours. It is then raked down and spread in layers 3 or 4 inches deep on the shelves in the kiln. This is heated by the producer gas burning within it, the shelves being arranged so that the burning gas passes over the lime on each shelf. Great stress is laid on the scrubbing action of the producer flame traversing the spaces between the shelves. The lime on each shelf is carefully turned once every half hour by means of a rake introduced at the doors forming the front of the kiln. The burning is finished in from four to eight hours, the charge of lime is withdrawn, and, unless the original lime was free from clinker, slaked while still hot. The process involves the frequent manipulation of the lime, but in careful hands will yield consistently a product containing not more than 8 per cent. of calcium carbonate. The second process, under Stokes' patents, is designed to avoid as far as possible the handling of the lime during burning, and the labour required is very little. The plant consists of a cylinder about 50 feet in length and 5 feet internal diameter, lined with firebrick, and set at a slight inclination to the horizontal on rollers, on which it revolves at the rate of about 1 revolution per minute. The gas from a producer passes in at the lower end of the cylinder, and is there supplied with the air for its combustion. The spent lime is raised by an elevator to the upper end of the cylinder, and is fed into it automatically. The upper 8 feet of the cylinder is larger in diameter than the remainder, and forms a chamber in which the lime is retained until it has parted with the bulk of its moisture. As the cylinder revolves the lime passes automatically out of the chamber and down to the lower end of the cylinder, meeting the flame of the producer gas, which by radiant heat raises it and the exposed parts of the cylinder lining to a high temperature. The passage of the lime down the cylinder takes from half an hour to an hour, according to the rate of revolution, which must be proportioned to the rate of feed and the character of the spent lime. The lime drops from the burning cylinder into the upper end of a second similar inclined cylinder, up which the secondary air for the combustion of the producer gas passes. This lower cylinder also revolves and serves the purpose of cooling the lime, which gives up its heat to the air passing up for the combustion of the gas in the upper cylinder. The lime passes out of the cooling cylinder into trucks, in which it is conveyed to the slaking floor. A small engine is required to turn the cylinders and work the elevator; the supervision needed is small, and the labour is reduced to a minimum. As the labour required does not rise in proportion to the size of the plant, it is especially suitable for large works, where spent lime can be supplied to produce 1 to 2 tons of burnt lime per hour. The process is continuous, and the plant is equally adapted to the burning of chalk. The spent lime or chalk passes through a crusher, in which it is reduced to a rough powder before it enters the cylinder. In its passage down the burning cylinder every particle becomes exposed to the flame of the gas. Other schemes have been proposed for the reburning of gas lime, but only the application of the Yeadon revolving retort (see p. 63) need be mentioned here. In any plan for burning lime, arrangements must be made for the removal of the carbon dioxide evolved by the decomposition of the calcium carbonate from the vicinity of the material, or the whole of the carbonate will not be decomposed whatever the temperature employed. Practically, this removal of the carbon dioxide from the atmosphere surrounding the material is generally effected by a stream of furnace gas passing over it.

Testing Chalk.—The testing of chalk and lime on a gas works is not usually very exhaustive. The chalk should be as nearly as possible pure calcium carbonate, in a slightly moist condition. It should not contain much magnesium, and must on no account contain more than 5 per cent. of silicon, aluminium, and iron.

The less of these ingredients the better will be the lime produced. The lime is seldom tested except for the amount of calcium carbonate present. If the nature of the chalk and fuel from which it is produced is unknown, it should also be tested occasionally for silicon, aluminium, and iron. The amount of carbonate present in lime may be ascertained by the ordinary methods for the estimation of carbonic acid as given in Fresenius' *Quantitative Chemical Analysis.* Where an accurate determination is required, the method of absorption tubes should invariably be used. These tubes may be filled and used precisely in the manner described by Fresenius, but special care must be taken that the calcium chloride used is free from alkalinity, and that the soda-lime tube is large enough. The author is in the habit of using an apparatus arranged as follows:—Following the evolution flask is a train of bulbs, containing a little concentrated sulphuric acid, then a U-tube containing pumice saturated with sulphuric acid, then a tube containing pumice impregnated with sulphate of copper dehydrated at 150° C., then a small U-tube containing sulphuric-acid pumice, then Liebig's bulbs containing a strong solution of potash, followed by a calcium-chloride U-tube, and that by another U-tube filled with calcium chloride, and this by bulbs or a bubbling tube containing strong potash solution. The potash bulbs and the calcium-chloride tube following are weighed together, before and after the evolution of the gas, with the usual precautions. To connect up to the inlet of the evolution flask whilst air is being drawn through the apparatus, are two bubbling tubes charged with potash solution. Of chalk or spent lime half a gram is a convenient quantity to take for the estimation; of well-burnt lime 2 grams. The weighed potash bulbs and U-tube will generally serve for two or three estimations before they need recharging. When spent lime or reburnt spent lime is being tested, the sulphate of copper tube must be of great capacity, and the sulphuretted hydrogen must be retained by it, as well as the hydrochloric acid vapours. A rough approximation to the amount of sulphide in the lime may be obtained by weighing the copper sulphate tube before and after the experiment, but it must be remembered that the figure so obtained is too high. The sulphuretted hydrogen may be oxidized in the evolution flask by adding solution of potassium chromate with the hydrochloric acid. The copper sulphate tube will then only be needed to catch the hydrochloric acid carried forward. For an accurate estimation of sulphide as well as carbonate in spent or reburnt lime, bulbs containing solution of arsenious acid or acidified solution of cadmium chloride must be placed at the beginning of the train of apparatus, and the sulphide obtained weighed as such, or oxidized to sulphate, and the latter precipitated with a barium salt. The use of sulphuric acid drying tubes avoids any risk of absorption of carbonic acid by alkaline calcium chloride. Many operators prefer potash bulbs to soda-lime tubes for the absorption of carbonic acid, and they certainly are easier of preparation. The U-tubes should be the variety, with hollow glass stoppers ground in, which will be found to weigh true after being laid aside for some days while charged. Geissler's bulbs and drying tube may advantageously be substituted for the Liebig bulbs and U-tube.

The methods for the estimation of carbonic acid in a carbonate, which depend on the loss of weight through evolution of the gas, are only accurate when tolerably pure chalk or lime is under examination. For spent lime or reburnt gas lime they give utterly fallacious results. In all cases, where a number of estimations have to be made, the method of absorption bulbs or tubes will be found little less rapid of execution, and its accuracy is indisputable.

An instrument largely used for the approximate determination of carbonate in lime is Scheibler's calcimeter. This instrument measures the volume of gas evolved in the decomposition by hydrochloric acid of the carbonate contained in a given weight of lime, and from the volume of carbonic acid evolved the percentage of carbonate in the lime is calculated. The calcimeter is illustrated, and the method of using it described in Fresenius' and most other text-books on quantitative analysis.

The author's experience of the calcimeter leads him to the conclusion that it cannot be relied upon for determination of small percentages of carbonate; but with care in working it is sufficiently correct for most technical purposes when the amount of carbonate is not less than 5 per cent. of the material. Estimations of carbonate by the measurement of the volume of gas evolved on decomposition can be carried out in many of the ordinary forms of gas analysis apparatus.

Testing Lime.—Lime may be tested either as such, or as the hydrate. It is perhaps best, for technical purposes, always to carry out the tests on the hydrated or slaked material, as it is not easy to obtain lime for testing in the anhydrous state owing to its great affinity for water. The slaked lime must be brought to the definite hydrate—*i.e.*, freed from uncombined water, by heating it at about 200° C. for an hour. The air that comes in contact with lime during drying or other preparation for testing should, if possible, be freed from carbonic acid; if this cannot be done the lime should be exposed to the air as little as possible. It is evident that the state of hydration of the lime affects the results of the determinations; but for comparative purposes, it is sufficient to dry the samples under similar conditions as to temperature and duration of heating on all occasions. A sample, consisting of 90 per cent. of pure quicklime (CaO) and 10 per cent. of calcium carbonate ($CaCO_3$) would, if exactly slaked to the hydroxide [$Ca(OH)_2$], show a percentage of calcium carbonate on the slaked sample of about 8·4 per cent. With samples containing higher percentages of carbonate the difference is less marked, nevertheless all analyses should be calculated to the same basis for comparative purposes if the samples cannot be tested in the same state of hydration. Unfortunately, neglect of this simple precaution often causes confusion in analyses made for technical purposes. The analysis of lime for other ingredients than carbonic acid is carried out according to the ordinary methods of quantitative analysis, for which the general text books on the subject must be consulted.

Removal of Sulphuretted Hydrogen.—Action of Ferric Oxide.—The next purifying material to be considered is ferric oxide. This is used solely for the absorption of sulphuretted hydrogen, and always in the hydrated state. The anhydrous ferric oxide appears to be quite unfitted for gas purification, and the suitability of hydrated oxide is determined more by its physical condition than by its chemical composition. The reaction on which the removal of sulphuretted hydrogen from gas by ferric hydrate chiefly depends is expressed by the following equation:—

$$Fe_2O_3,H_2O + 3H_2S = Fe_2S_3 + 4H_2O.$$

But besides this reaction, the following also occurs:—

$$Fe_2O_3,H_2O + 3H_2S = 2Fe_2S + S + 4H_2O.$$

Lewis T. Wright has investigated the action of sulphuretted hydrogen on hydrated ferric oxide,[*] and concludes that from 17 to 30 per cent. of the sulphuretted hydrogen absorbed by oxide is taken up in accordance with the second equation, and the remainder in accordance with the first. The proportion in which the two reactions occur is approximately afforded by fouling oxide and removing the sulphur thrown down by washing with carbon disulphide, the air being carefully excluded throughout to prevent the oxidation of the iron sulphide and consequent deposition of sulphur. On evaporating the carbon disulphide, the sulphur dissolved by it remains, and is the quantity of sulphur thrown down in accordance with the second equation, and is a measure of the extent to which that reaction took place. The iron sulphides are very unstable in an atmosphere containing oxygen, being readily oxidized with the liberation of water and sulphur. Consequently, there is no simple method for the determination of their relative amounts in a mixture.

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[*] *Journ. Chem. Soc.*, 1883, p. 156.

The most active form of ferric oxide to sulphuretted hydrogen is the freshly precipitated hydrate in suspension in water. Under favourable conditions the whole of this may be converted to sulphide, and, consequently, we may suppose that the hydroxide, $Fe_2(OH)_6$, would form a very good purifying material. Unfortunately, this body is very unstable, though with care it may be obtained in a dry state. On heating, however, at 100°, it loses water. and gradually approaches to the composition Fe_2O_3,H_2O. The amorphous compound represented by this formula may be obtained artificially in a pure state in other ways. On continued heating at 100° C. the precipitated oxide is said to lose more water, and become $2Fe_2O_3 + H_2O$, a modification soluble with difficulty in acids. On ignition, hydrated ferric oxide passes into the anhydrous oxide. The receptivity of oxide of iron for sulphuretted hydrogen appears to diminish approximately with the amount of combined water, and we find the anhydrous oxide is almost useless for gas purification. Attempts have often been made to bring the anhydrous oxide into a suitable state of porosity and division for the ready absorption of sulphuretted hydrogen; but though many operators have claimed good results for the material after some preparation, such oxide has never been extensively adopted for gas purification.

Testing Bog Ore.—The variety of oxide most in favour with gas managers is the natural bog ore, of which extensive deposits exist in the peat bogs of the north of Ireland. This ore contains about 30 per cent. of ferric oxide, and 55 per cent. of moisture driven off at 100° C., combined water approximately equal to that required to form a monohydrate with the iron oxide, and a residue, chiefly of organic matter, in the form of roots and decayed vegetable fibre. In analyses of this oxide it is usually assumed that the whole of the soluble iron exists as the monohydrated oxide (Fe_2O_3,H_2O), and the results are stated in percentages of that body. The determinations of the iron and water in the ore are, generally, the only ones made, the decision as to the quality of the oxide, from the gas managers' point of view, chiefly resting on the results empirically obtained on submitting a small quantity of the material to the action of a stream of foul gas. The determination of the iron in oxide of iron is generally carried out by the following method :—The oxide is roughly pulverized, and about 2 grams carefully weighed out. This amount is boiled for two to three hours with 50 c.c. concentrated hydrochloric acid and 50 c.c. water, in a flask fitted with an inverted condenser. At the end of that period the condenser tube is washed into the flask, and the contents of the flask diluted to about 200 c.c., filtered, the filter paper thoroughly washed with hot water, and the filtrate and washings made up to 500 c.c. at 60° F. with distilled water. From this solution 125 c.c. is taken by a pipette, magnesium, or zinc free from iron, added, until the change in colour indicates that the iron is completely reduced to the ferrous state, and the excess of magnesium or zinc has completely dissolved. Some operators prefer other reducing agents — such as sodium thiosulphate or stannous chloride. Care must be taken not to use an excess of the latter agent. If the exact point at which the reduction is complete is not very clear, a few drops of potassium thiocyanate may be added to the liquid, and the disappearance of the red colour produced by that salt with ferric iron will show that the whole of the iron is reduced. A little experience will, however, generally suffice to enable the operator to say exactly when the yellow colour indicating the presence of ferric salt is discharged, and the use of an indicator will then become unnecessary. When zinc or magnesium is used, an excess of the reducing agent is harmless, provided all is dissolved before commencing to titrate the solution. The standard solution generally used for the titration is decinormal bichromate of potash. Pure potassium bichromate in crystals is tolerably easily obtained, and, if roughly powdered and dried in the hot-water bath, will serve for making up the standard solution with exactitude. 4·913 grams of the dry salt are dissolved in a litre of water to give the decinormal solution. If any doubt exists as to the purity of the potassium bichromate, the strength of the standard solution should be checked by titration against a weighed quantity of pure iron wire. The point at which a ferrous solution is completely oxidized by bichromate can only be ascertained by the use of an external indicator. This indicator is a freshly-prepared solution of potassium ferricyanide, which gives a blue colour with ferrous salts. Drops of the ferricyanide solution are scattered on a glazed, white tile, and a drop of the iron solution undergoing titration is brought, on the end of a glass rod, into contact with one of the drops of ferricyanide solution, from time to time, as the bichromate is added to the iron solution. A blue colouration is formed in the drop of ferricyanide as long as the oxidation is incomplete, but when ferrous salt is no longer present, only a brown tint is formed in the ferricyanide. To find the exact point of complete oxidation when the amount of iron in solution is not approximately known, it is best to make a rough preliminary titration, and then, with a second portion of the iron solution, to titrate cautiously, as the point of oxidation is approached, testing a drop of the solution in a drop of ferricyanide solution after each addition of 0·2 c.c. of standard bichromate. By this means the exact point of complete oxidation may be found with ease and certainty. If the method of titrating with bichromate, using ferricyanide as an indicator, is new to the operator, he should proceed first on iron solutions of known strength until the results show that he has acquired sufficient familiarity with the method to use it with accuracy. The calculations requisite for finding the percentage of iron from the amount of bichromate used are readily explained. 56 grams of iron require 8 grams of oxygen for conversion from the ferrous to the ferric state. 1 c.c. of decinormal bichromate solution yields $\frac{8}{10,000}$ grams of oxygen, or sufficient to convert $\frac{56}{10,000}$ grams of iron from the ferrous to the ferric state. $\frac{56}{10,000} = 0{\cdot}0056$. Therefore, the number of cubic centimetres of decinormal bichromate solution used in completely converting an iron solution from the ferrous to the ferric state, multiplied by 0·0056, will give the amount of iron present in grams. If it is wished to know at once the equivalent amount of ferrous oxide, the multiplier is 0·0072 instead of 0·0056; if the amount of ferric oxide, the multiplier is 0·0080. Analyses of bog ore are frequently stated in percentage of hydrated ferric oxide (Fe_2O_3,H_2O), in which state the whole of the iron is assumed to be. The multiplier for converting the number of cubic centimetres of decinormal bichromate used into grams of this monohydrate (Fe_2O_3,H_2O) is 0·0089.

When 2 grams is the amount of bog ore taken for solution, and one-fourth only of the total solution is used for titration, the amount of ore in that quantity is 0·5 gram. If the number of cubic centimetres of bichromate used in titrating this quantity is multiplied by $(0{\cdot}0089 \times 200) = 1{\cdot}78$, the result is the percentage of ferric hydrate (Fe_2O_3,H_2O) in the oxide. The use of a constant weight of ore for the determinations simplifies the calculations, and is the method usually adopted in gas works laboratories, where a large number of tests have to be made rapidly. The method of extraction by boiling with hydrochloric acid given above, usually suffices to dissolve out all the iron from the descriptions of oxide offered to gas managers. The volumetric estimation of iron in bog oxide may also be carried out with decinormal solution of potassium permanganate in place of potassium bichromate. It is advisable for the purpose to have the iron in solution in sulphuric instead of hydrochloric acid. No external indicator is needed; but certain precautions must be observed in working with permanganate, for which the general text-books must be consulted, though some information may be gleaned from the method of testing Weldon mud, described on p. 99. The method presents no very obvious advantage over that with bichromate, and the standard solution is more difficult of preparation and less stable.

The moisture held mechanically in bog oxide may be estimated with tolerable accuracy by drying about 20 grams of the roughly pulverized material in a hot-water oven for three or four hours, weighing carefully before and after. Some operators prefer to take a larger quantity of oxide for the estimation of moisture, and to weigh from the dried sample that required for the iron estimation. This method diminishes the errors inherent in the weighing of small quantities of moist material, and is likewise applicable to the estimations of moisture and manganese dioxide in Weldon mud.

Purification Value of Ferric Oxide.—Some artificial oxide of iron, obtained by precipitation of iron dissolved in sulphuric acid with ammonia, shows when moderately dry an affinity for sulphuretted hydrogen equal to that of the best bog oxide. This oxide appears to be in the best condition for purification purposes when about 20 to 30 per cent. of moisture is present. Lewis T. Wright found bog oxide to answer best with 10 to 20 per cent. of moisture, but some engineers have considered a smaller amount more favourable. As generally used, when new the bog oxide contains more than 20 per cent. of moisture, and most managers prefer it in this condition. The nature of the particular sample must largely determine the most suitable degree of moistness, and this can be ascertained by small scale experiments. It is customary to add some such material as sawdust or wood-chips to oxide before putting it in the purifier for the first time. The object of the addition of such inert material is twofold—firstly, to render the oxide more permeable by gas; secondly, to moderate undue activity of action. The amount added should be as little as will meet these ends, and is regulated by the amount of organic fibre in, and the physical state of, the oxide. It is a mistake to suppose that fibre is deleterious to oxide; it is a most important factor in presenting the material to the gas in a sufficiently finely-divided state, and is the cause of the immense superiority of native bog ore over most artificial oxides. The use of sawdust, however intimately it may be mixed with the oxide, can never entirely replace the natural fibre of bog ore, as the latter causes a greater porosity of the material, and consequently exposes a far greater surface to the action of the gas. Moisture is also an important factor in forming the requisite physical state of the oxide; but generally speaking, only so much added water is required as is necessary to aggregate the oxide sufficiently to prevent it falling through the grids in the purifier. The water of hydration is probably chiefly responsible for the superiority of hydrated over anhydrous oxide on account of the greater porosity it gives to the material.

The final test of the suitability of oxide for the purification of gas is the fouling and revivification of small quantities of it, in imitation of the treatment to which it will be subjected on the large scale in the purifier, and the estimation of the amount of sulphur assimilated by it at each fouling. For the testing, about a quart of the oxide is brought to the estimated proper degree of moistness, a small sample is retained for the determination of the moisture, and a vessel of the shape shown in Fig. 21 is charged from the remainder, a plug of cotton wool being placed in the constriction of the vessel to prevent the oxide falling into the lower part. Glass tubes passing through corks in the orifices of the vessel form the inlet and outlet pipes, and the lower one is connected by caoutchouc tubing to a cock on the outlet main of the work's scrubbers. A stream of washed and scrubbed, but otherwise unpurified, gas is then allowed to pass through the oxide for twelve hours, when the vessel is disconnected and the oxide laid out in a small heap. If the material is even moderately active, the exposure to the air will cause rapid oxidation of the iron sulphides with considerable development of heat. Towards the end of the revivification, the material should be turned over a few times until all the black sulphide has disappeared from it. A small average sample should be taken from the heap, dried in the hot-water bath, and reserved for the estimation of the amount of sulphur present in it by the method described for

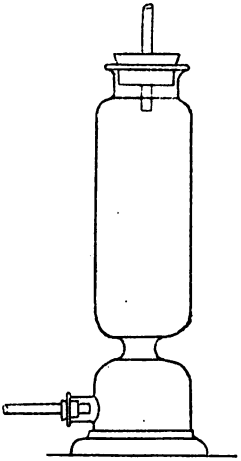

Fig. 21.—Vessel for fouling small samples of oxide, &c.

the evaluation of spent oxide in Chapter xi. The remainder of the oxide is moistened to the required degree, and returned to the fouling vessel for a further twelve hours' treatment with foul gas. The oxide is again revivified in a precisely similar manner, and an average sample taken, dried, and used for the estimation of the sulphur content. The material is fouled and revivified a third time, and the amount of sulphur in a dried sample ascertained. Three successive foulings are generally considered sufficient to give a true indication of the value of a sample of oxide; but it may be necessary to repeat the series with the material more or less moist than at the first tests, to arrive at the most favourable results for each sample examined. The amount of moisture in the oxide as put into the fouling vessel should always be ascertained, and the tests for sulphur should always be carried out on dried samples. If the samples used for sulphur estimations are weighed in the condition in which they are taken from the purifier comparisons become useless, as the only legitimate basis on which to make them is on the dried material. The amounts of sulphur that may be expected in good oxide examined in this manner are:—

After the first fouling, ...	14 to 18 per cent.
,, second ,, ...	20 to 25 ,,
,, third ,, ...	24 to 31 ,,

In addition to the sulphur set free during fouling in the manner described on p. 95, the revivified oxide contains as free sulphur almost all the sulphur absorbed as sulphides. The action of the oxygen of the air in converting the sulphides to oxide is very simple, and may be expressed by the equations:—

$$\mathrm{2Fe_2S_3 + 3O_2 = 2Fe_2O_3 + 3S_2}$$
$$\mathrm{12FeS + 9O_2 = 6Fe_2O_3 + 6S_2.}$$

These equations at least represent the final result of the exposure of properly fouled oxide to the air. In the actual purifying vessels results comparable with those obtained on the small scale may be expected, but care must be taken that the oxide is properly prepared to give the most favourable results before it is put in. The oxide is on the working scale generally fouled and revivified from ten to twelve times, and should, before being discarded for further use, be loaded with 50 per cent. of free sulphur. When so loaded, its purifying capacity becomes much diminished by the large bulk of inert material in it, and it is more economical to dispose of it to the sulphuric acid maker than to continue to use it for purifying purposes. The estimation of free sulphur in spent oxide is described in Chapter xi.

Weldon Mud and Manganese Dioxide.—Weldon mud is a material of comparatively recent introduction for gas purification. Its activity is due chiefly, if not entirely, to the manganese dioxide it contains. Manganese dioxide has been suggested as a suitable material for removing sulphuretted hydrogen from the early days of the gas industry, being generally mentioned as being equally effective as ferric oxide. It does not appear to have been adopted on the large scale however. But latterly E. Donath has recalled attention to it,* and states that all the oxygen of the oxide may be replaced by sulphur by passing sulphuretted hydrogen over it, the flesh-coloured manganese sulphide being the product. It has, however, been difficult to obtain the manganese dioxide in a suitable physical condition for the complete removal of sulphuretted hydrogen from coal gas by its agency, and the introduction of Weldon mud to gas works marks the beginning of the practical application of manganese dioxide to gas purification. The use of an artificially prepared hydrated oxide of manganese, such as "Weldon mud," for the desulphurization of gases was patented in 1887 by J. J. Hood and A. G. Salamon.† These gentlemen proposed at one time to use Weldon mud for the removal of other impurities than sulphuretted hydrogen from coal gas, but their subsequent experience has not apparently led them to recommend its use for other purposes than the extraction of sulphuretted hydrogen from gases.

Preparation of Weldon Mud.—Weldon mud is produced in works where manganese dioxide is used for the liberation of chlorine from hydrochloric acid for the manufacture of bleaching powder. When the original manganese dioxide is completely dissolved, and the acid liquid contains chiefly manganese chloride, it is neutralized with calcium carbonate, and the oxide of iron and other deposited matters are allowed to settle. The clear liquid is mixed with milk of lime in a proportion more than enough to throw down the whole of the manganese by about one-third its content of lime. A current of air is blown through the liquid containing the precipitated manganese hydroxide in suspension while its temperature is kept at about 60° C. In the presence of excess of lime, the greater part of the hydroxide is thereby converted to dioxide. On allowing the manganese to settle from the blown liquor and removing the supernatant solution of calcium chloride, the Weldon mud remains. In the ordinary course this mud is used in place of fresh manganese oxide in the chlorine stills. It consists chiefly of manganese dioxide, manganese monoxide, calcium chloride, and calcium oxide with a large quantity of water. If partially dried, and then used for gas purification, this mud would become very wet owing to the moisture attracted by the calcium chloride. The patentees of the Weldon mud purification process therefore recommend the washing of the mud until the calcium chloride is reduced to 2 or 3 per cent.* The prepared mud as now delivered for gas purification contains from 48 to 57 per cent. of water, and 23 to 29 per cent. of manganese dioxide, the remainder being chiefly lime, calcium chloride, silica, and protoxide of manganese. The percentage of manganese dioxide in the dried material is tolerably uniform, being about 56 to 58, but the large quantity of water present in the mud as delivered is subject to variations according to the atmospheric conditions, and with it varies inversely the amount of manganese dioxide. Hence care should be taken that representative samples of the moist mud are tested for moisture and manganese dioxide, immediately after they are taken, as on standing in a warm place moisture separates from the mud, and collecting in globules on the upper part of the containing vessel is with difficulty properly re-incorporated with the mud. Where discrepancies in determinations of manganese dioxide in Weldon mud occur, they may often be accounted for by the different contents of water of the samples, and a reference to the percentage of manganese dioxide on the dried material will generally throw light on conflicting results. Needless to say, where Weldon mud is bought and sold on the amount of manganese dioxide per ton of moist material, average samples should be taken at the time of weighing, preserved from exposure, and tested as quickly as possible after being taken. When a representative sample has to be kept some time before the determination is made it should completely fill the containing bottle, which must be tightly corked, and well sealed. The bottle should be kept in a moderately-cool place. The nature of the material would indicate to chemists the necessity of such precautions in sampling and testing, if disputes are to be avoided. The manganese dioxide being the constituent of Weldon mud which gives the latter its value for gas purification, it generally suffices for the evaluation of the material to estimate the amount of that ingredient. This estimation is made by the method adopted by the alkali makers or some slight modification thereof. The strength of a solution of ferrous sulphate acidified with sulphuric acid is determined by oxidation with standard bichromate or permanganate solution; a weighed quantity of the Weldon mud is dissolved in a known volume of the acid ferrous solution, and the unoxidized ferrous salt determined by the standard bichromate or permanganate. The oxidizing effect of the Weldon mud is thus known, and thence the percentage of manganese dioxide contained in it is calculated. As the determination is more familiar to alkali-works chemists than to gas-works chemists, one method may with advantage be given in detail here.

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* *Dingler's polyt. Journal*, vol. cclxiii., p. 248.

† English Patent, No. 10,127, July 19th, 1887.

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* *Journ. Soc. Chem. Ind.*, 1888, p. 3.

Mode of Testing Weldon Mud.—A decinormal solution of potassium permanganate is made by dissolving 3·156 grams of the pure dry salt in a litre of distilled water at 16° C. When the salt is completely dissolved, the strength of the solution is checked by titrating against a known weight of pure iron wire dissolved in dilute sulphuric acid, with the usual precautions and correction for impurity in the iron wire, for which the text-books on volumetric analysis must be consulted. 0·112 gram pure iron requires 20 c.c. decinormal permanganate solution for its oxidation from the ferrous to the ferric state. A convenient substance for standardizing potassium-permanganate solution is sodium oxalate. 0·134 gram of the pure dry salt is equivalent to 20 c.c. decinormal permanganate. The sodium oxalate should be titrated in solution acidified with sulphuric acid at a temperature of about 60° C. The end reaction is then very sharp. The permanganate solution, if not exactly decinormal, may be made such by addition of the calculated amount of the salt or water, or may be used and correction made for the error as found by titration against the iron wire or sodium oxalate. Standard permanganate must not be allowed to come in contact with organic matter such as caoutchouc, and in any case it is advisable to check its strength once a month. Unless the strength of the permanganate is exactly decinormal, or the error is accurately known, it is useless to attempt estimations with it. A solution of ferrous sulphate is prepared by dissolving 100 grams of the pure, clean, crystallized salt in distilled water, adding 100 c.c. of pure concentrated sulphuric acid, and making up to a litre at 16° C. with distilled water. The strength of this solution is ascertained by titrating 20 c.c. with the decinormal permanganate. If the ferrous sulphate was pure and unoxidized, about 72 c.c. of the permanganate will be required to oxidize 20 c.c. The amount of permanganate required is noted, and must be re-ascertained every day that the iron solution is used, as the latter gradually oxidizes, even though kept in a closely stoppered bottle. About 0·5 gram of the Weldon mud is weighed out accurately, washed into a small flask, and 20 c.c. of the iron solution added (preferably from the same pipette as was used in standardizing it). The solution of the Weldon mud is aided by gentle heating and trituration by a glass rod against the bottom of the flask. When the mud is completely dissolved the solution is titrated with the standard permanganate, and the volume of the latter required for its oxidation noted. The following are figures actually obtained in an analysis:—

20 c.c. ferrous solution required, . .	70·5 c.c.	$\frac{N}{10}$ permanganate solution for oxidation.
0·5 gram Weldon mud was dissolved in 20 c.c. ferrous solution, which then required	42·8 c.c.	,, ,, ,,
Therefore, the Weldon mud contained manganese dioxide equivalent to .	27·7 c.c.	$\frac{N}{10}$ permanganate solution.

But 1 c.c. decinormal solution is equivalent to 0·00435 gram manganese dioxide, therefore, 0·5 gram Weldon mud contained 27·7 × 0·00435 gram manganese dioxide. The Weldon mud, therefore, contained nearly 24·1 per cent. of manganese dioxide. This sample contained 57·1 per cent. of water; therefore, the percentage of manganese dioxide on the dry basis was 56·2. It is generally advisable to perform two determinations of the manganese dioxide in each sample, and if the results are within 0·2 per cent., to take the mean. If the variance is greater, a third determination should be made. It is advisable to remove the desiccating material from the balance case when such a moist material as Weldon mud is being weighed. Decinormal bichromate may be used instead of permanganate solution if preferred, while many analysts consider seminormal solution sufficiently delicate for the determination. The precise strength of the ferrous sulphate solution is immaterial, but it should be ascertained shortly before each determination.

The affinity of particular samples of Weldon mud for sulphuretted hydrogen may, if desired, be ascertained by fouling and revivification, in a similar manner to the testing of oxide as described on p. 95. In estimating the sulphur present after each fouling, it is desirable to remember the fact that a higher percentage of sulphur will be found, in most cases, if the spent mud be treated with hydrochloric acid, according to a method described in Chapter xi., instead of being directly extracted by carbon disulphide.

Action of Weldon Mud.—The action of sulphuretted hydrogen on the manganese dioxide of Weldon mud is very similar to its action on ferric hydrate. The flesh-coloured sulphide of manganese results, together with water, from the action. This sulphide, especially when moist, is very readily oxidized, with evolution of heat and deposition of free sulphur. The calcium oxide of the mud becomes converted eventually to sulphate, as does also a small amount of the manganous oxide. The action of Weldon mud on sulphuretted hydrogen appears to be more vigorous than that of bog oxide, and mere traces of the gas are more completely absorbed by the former material. In three foulings of Weldon mud containing 56·2 per cent. of moisture and 25·3 per cent. of manganese dioxide, the following percentages of sulphur in the dry material, after revivification, were found (by simple extraction with carbon disulphide):—

After fouling and revivifying, the dried mud contained 28·1 per cent. sulphur.

After second fouling and revivifying, the dried mud contained 34·8 per cent. sulphur.

After third fouling and revivifying, the dried mud contained 40·6 per cent. sulphur.

The application of Weldon mud and its advantages over oxide of iron are alluded to in the description of the scheme of gas purification that follows.

Other Purifying Materials.—The materials in common use for the purification of gas have now been briefly discussed. Sundry other substances have at times been used, such as other metallic oxides than those named, heated clay, &c., but they are no longer deemed serviceable. Allusion will be made later on to the principles of the wet methods of purifying gas, which depend on the absorption of carbonic acid, sulphuretted hydrogen, and carbon disulphide by ammonia and its compounds, derived originally from the gas itself; but the extent of their adoption at present will not permit of their ranking by the side of the common method of purification which is now described.

Grids and Purifiers.—For the support of the materials used in the dry or ordinary system of gas purification, wooden grids are placed in layers extending across the whole area of the purifying vessel. These vessels are usually oblong or square in form; in old works circular ones are sometimes found. The dimensions vary according to the amount of gas for which they are designed; but in large works where several sets are in use, and the vessels in each set are made as large as is consistent with convenient working, each vessel will be from 30 to 40 feet square, or about 30 feet by 40 feet, and about 6 feet in height. The purifier is usually of cast iron, and the lid of sheet iron, supported by angle irons and trussed internally by tie-rods if necessary. The sides depending from the lid dip into the water-seal or lute in the purifier, the depth of which varies to suit the maximum pressure at which the gas is driven through the vessel. In large works the lute will give a water-seal of 36 inches, the channel being slightly deeper than that. When the purifier is in action the lid is held down by suitable bars passing over the corners and secured by clamps to the sides of the vessel. Various contrivances are adopted for raising and supporting the lids when the purifier requires emptying. An apparatus frequently used consists of two standards, each mounted on two grooved wheels, which traverse rails on each side of the purifier. The standards are kept apart at the top by a stout connecting girder. On one standard is a winch, which by cog-wheels or pulleys is connected to a hook or hooks from the girder attached to the purifier lid to raise it. When raised the standards are pushed along the rails until the lid is clear of the vessel to which it belongs, and no obstruction is offered by it to the work of the purifying gang. The materials are very generally taken from the vessels in sacks and shot where desired; but in some vessels, arranged on the upper floor of a building, an outlet is provided in the bottom of the vessel through which the spent material is thrown into trucks on the ground floor. Likewise, the materials are carried into the vessels in sacks, as a rule, and levelled by means of a rake on the grids. But where a floor above that on which the purifiers stand is available, the fresh materials are raised to it by an elevator, and dropped through a flexible shoot, which is carried by the man in charge over the whole surface of the purifier, any inequalities in the deposition of the material being suppressed by means of a rake. These plans save much labour, but entail large expenditure on the building containing the vessels. The placing of the purifiers on a floor above the ground level has, however, the great advantage of leaving the

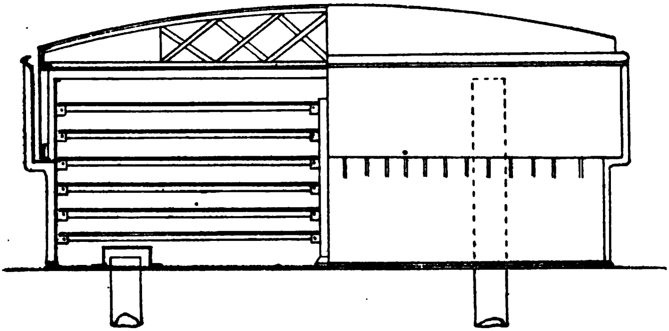

Fig. 22.—Ordinary gas purifier; part section, part elevation.

valves and connections visible, and readily accessible from below. An ordinary purifier, partly in section, partly in elevation, is shown in Fig. 22, and the arrangement mentioned above of the purifiers on the middle of the three floors in the house is shown in Fig. 23. The floor space on the upper floor can be used for the preparation or storage of the materials used.

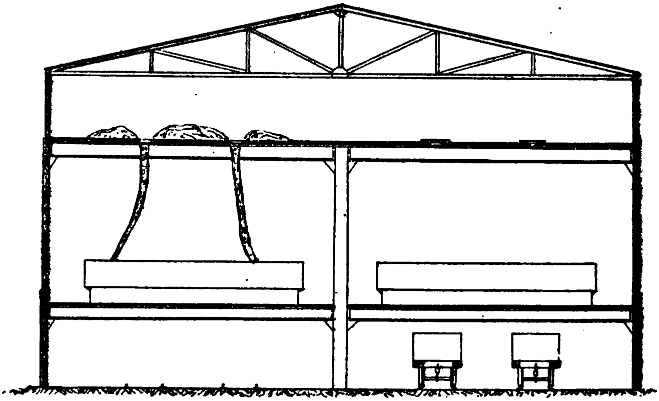

Fig. 23.—Cross-section of three-floor purifying house.

The grids are supported on a light framing of angle iron in the purifier, and are, of course, taken out as they become cleared in the emptying of the vessel, and replaced as wanted when the vessel is being charged. They consist of strips of pine wood 1½ to 2 inches deep, and ½ inch wide, bolted together with ½-inch bolts, spaces of ⅝ inch being secured between the strips by the insertion of small blocks of wood of that thickness, through which the bolts pass. A drawing of a typical grid is given in Fig. 24. Cast-iron grids are occasionally used in place of the more usual wooden ones. In large works the purifying vessels

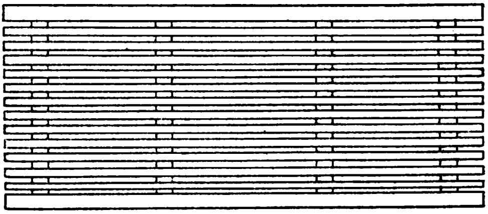

Fig. 24.—Purifier grid.

will each contain five or six tiers of grids, the material being spread to a thickness of about 8 inches on each. Where six to eight vessels, each containing this depth of material on each of the five or six tiers, are used, the pressure at which the gas enters the purifiers is usually equal to that of a 20- to 30-inch column of water.

Scheme of Purification.—The removal of carbonic acid from gas is the duty of the first and often of both the first and second vessels in the series of purifiers. Lime carefully slaked is loaded into the vessel and levelled on each tier of the grids. In many works the lime is used in a comparatively dry state for convenience in handling, but it must be remembered that its full absorptive power is not thereby attained. When possible the lime should be used in such a state of moistness that it agglomerates readily, and forms a soft pasty mass when pressed together. Generally, however, it will be more convenient to handle the lime in the condition obtained on slaking with the quantity of water mentioned on p. 85. About 6 cubic yards of quicklime brought to that degree of moistness will remove the carbonic acid from a million cubic feet of ordinary coal gas, or about 70 lbs. of quicklime will purify the gas from 1 ton of common coal. The gas entering the lime purifier contains both sulphuretted hydrogen and carbonic acid. The strongly basic nature of the lime causes it to combine with both these gases, and so long as it is not nearly neutralized by them, both are removed from the gas. When, however, the lime has become nearly saturated, the more stable nature of calcium carbonate over calcium sulphide is shown by the gradual decomposition of the latter salt by the carbonic acid coming in with the gas. Sulphuretted hydrogen is given off on the decomposition, and passes forward with the gas to be removed from it at a later stage of the purification. The superior affinity of lime for carbonic acid thus enables a vessel to be entirely converted to carbonate, although sulphuretted hydrogen is passing in with the gas. As the lime becomes saturated with carbonic acid, that gas begins to pass on unabsorbed, and the course of the fouling of a lime vessel may be traced by testing the gas issuing from cocks placed above each tier in one side of the purifier. This testing is carried out by the simple process of bubbling the gas from a capillary tube through perfectly clear lime or baryta water. The lime water is prepared by agitating boiled water with slaked lime, and decanting off the clear liquid which separates after some hours of rest. The gas to be tested is bubbled through the lime water contained in a glass tube, to which a cork is loosely fitted to hinder free contact with the air.

If the gas is free from carbonic acid, no cloudiness will be visible in the lime water after a minute's bubbling; if carbonic acid is present in appreciable amount, a distinct cloudiness will rapidly become visible in the lime water. When traces of carbonic acid are found at the fourth or fifth tier of the first purifier, it is absolutely necessary to put a second lime purifier into action in succession to the first one which is nearly completely fouled. The first need not, however, be shut out until some time after carbonic acid has been found at its outlet, as by keeping it in action after this is noticed, the more perfect carbonization of the lime is ensured. It must, as a rule, be shut out in time to be discharged and recharged with fresh lime before the second purifier shows traces of carbonic acid at its fifth tier, as it is usually wanted to take the gas from the outlet of that vessel as soon as carbonic acid appears at that point. The two vessels are thus continually changing their relative positions with regard to the stream of gas passing through them, and unless their size is altogether inadequate for the quantity of gas passing, one can be emptied and recharged while the other is fully efficient. If this is impossible, a third vessel must be given to lime, and the three worked in rotation, one being recharged while the other two are in action. If the vessel is shut out of action immediately there is carbonic acid at the top tier, a considerable portion of the material will be sulphide, not carbonate, and the sulphur therein is not recoverable. In most cases, therefore, economy will point to the necessity for keeping a vessel in action until the lime is nearly wholly converted to carbonate, but where purifying room is cramped this is sometimes impossible. It may be taken as a cardinal rule that whatever "system" of purification is adopted, carbonic acid should not be allowed to pass out of the last lime vessel in the series, as it is likely to cause serious derangement in subsequent vessels. The lime in the vessels absorbs other substances besides carbonic acid and sulphuretted hydrogen, but necessarily only in small quantities. Cyanogen that has escaped the washers is taken up, and the sulphur compounds other than sulphuretted hydrogen are slightly diminished in amount. If air or ammonia passes into the lime purifiers with the gas, the actions are somewhat modified, and the judicious admission of either increases the amount of carbon disulphide absorbed from the gas in these vessels. The oxygen of the air probably converts some of the calcium sulphide or hydrosulphide in the purifier into the hydroxysulphide, which then absorbs carbon disulphide. Moist calcium sulphide also absorbs a portion of the carbon disulphide in gas, but like calcium sulphide the compound formed is decomposed by carbonic acid, and hence when vessels are completely carbonated, the quantity ultimately so absorbed is very small. Ammonia probably unites in the presence of lime with carbon disulphide, and calcium thiocyanate and calcium sulphide are the ultimate products of this reaction. The presence of much thiocyanate imparts a bright red colour to the spent lime. The blue and green tints of spent lime are due to iron from the chalk, fuel ash, and the water used in slaking. Oxygen converts calcium sulphide to thiosulphate, and various basic thiocarbonates are also present in spent lime.

From the above it will be gathered that sulphuretted hydrogen is driven out with the gas from the carbonate vessels, by the action of the carbonic acid on the calcium sulphide, and also as a product of minor reactions in which the carbon disulphide plays a part. Hydrated ferric oxide is commonly employed to absorb this sulphuretted hydrogen, and in most works two purifiers will be given to it. These are worked in a similar manner to the lime vessels, that is to say, the gas passes through the cleanest oxide purifier last; the first one in the series is recharged as soon as it is completely fouled, and the relative positions of the two vessels with regard to the stream of gas then become reversed. The reactions which occur between ferric oxide and sulphuretted hydrogen are given on p. 90. The material is disposed on the purifier grids in a similar manner to lime, and is generally considered most active when it contains about 15 per cent. of moisture.

Revivification of Ferric Oxide.—When oxide is completely fouled it is removed from the purifier in the same manner as lime, and spread on the floor of a shed to a depth of 18 inches for revivification. Revivification is the name given to the conversion of the iron sulphide to oxide by means of the atmospheric oxygen. This is attended with the production of heat, and very active oxide must be watched during the early stages of its revivification, lest the heat cause ignition of the sulphur or sawdust mingled with it. As the black colour disappears from the surface of the oxide, it should be turned over so as to expose fresh material to the action of the air, and this turning of the oxide must be carried out at intervals until all the black sulphide has disappeared from the mass. Revivification is then complete, and the revivified material may be again used for the removal of sulphuretted hydrogen from gas. The activity of the material is, of course, somewhat impaired by the sulphur deposited in it on each revivification. The action between sulphuretted hydrogen and good oxide is sharp and decisive, though oxide does not readily take out the last traces of sulphuretted hydrogen from gas. The material does not become unpleasantly moist in the purifiers, and the emptying of the vessels is not a specially disagreeable work.

Many attempts have been made to conduct the revivification of oxide of iron in the purifier itself. A method which naturally suggests itself is shutting out the vessel as soon as the oxide is fouled and, without raising the lid, passing air by means of an exhauster through the spent material. There is no difficulty in starting the revivification by this means, but considerable care is needed to secure the change with safety throughout the mass. The revivification is apt either to occur sluggishly and incompletely, or to take place with great vigour and consequent heating. By carefully regulating the amount of air admitted according to the temperature attained in the mass, the desired chemical change may be effected without undue slowness or celerity. Heating of the oxide to about 70° C. favours complete revivification; but if the temperature rises much higher, air should be blown through the vessel in largely increased quantities, or steam injected. The increased volume of air will carry away heat from the material; the steam will damp it and so hinder the reaction, which takes place most vigorously with dry oxide. Heating the material largely conduces to rapid revivification by the withdrawal of moisture from the mass. If during the revivification in the purifier the temperature rises much above 100° C., the deposited sulphur may be fused, and even caused to fire. The chief objection to this method of revivifying oxide in the purifier is the diminished porosity of the material, which is especially evident when the temperature has been high during revivification. The increased pressure thrown by oxide so revivified is very marked, and though various means have been suggested of diminishing this trouble, it and the risk attendant on the revivifying of a large mass of material in a closed vessel have prevented the extensive adoption of the system. Needless to say, evil-smelling gases are driven from the vessel during revivification by means of a stream of air.

Revivification of oxide while the vessel is in action was proposed many years ago, and has formed the subject of many patents. Air, proportioned in volume to the amount of gas, is continuously forced in with it, the air being, according to some patentees, previously carburetted by passing over heated tar or naphtha. This carburetting of the air employed, of course, avoids the loss of illuminating power due to the dilution of the gas with nitrogen, but entails expenditure on naphtha or the removal of the lighter constituents from tar. From 2½ to 3 per cent. by volume of air is theoretically required to be added to gas containing the common quantity of 600 to 700 grains of sulphuretted hydrogen per 100 cubic feet, to completely revivify the oxide while in action; and this is about the quantity that former experimentalists found empirically to be most suitable. Theoretically an oxide purifier, revivified by the continuous admission of the proper proportion of air with the gas, should remain active until the oxide is sufficiently loaded with sulphur for disposal to the sulphuric acid makers. But as a matter of fact, experience shows that this result cannot be reasonably expected in practice. The oxide is found to become less porous after it has remained in the vessel some time, during which it has been revivified *in situ*, and, consequently, throws a constantly increasing pressure. It soon becomes necessary to remove the oxide from the purifier and break up the masses, and as this will generally have to be done at least twice during the life of the oxide, the saving of expense over the ordinary method of using oxide is not very great when the expense of pumping and metering a proper proportion of air is considered. The higher temperature of an oxide vessel in which continuous revivification is proceeding favours its activity, and prevents the loss of illuminating power to the gas by the deposition of hydrocarbons in the vessel. The deleterious influence of the nitrogen of the air which remains in the purified gas is thereby masked, and to some extent compensated for. The use of pure oxygen in place of air suggests itself; but for the purpose of revivifying oxide *in situ* it has been little tried, though H. Veevers claims excellent results from its use.* The economy of the process is, however, open to question. Oxygen as an aid to gas purification is probably more effectively applied at other stages of the purifying, and its general use will be considered later. Where the oxide vessel is followed by "sulphide" vessels for the removal of carbon disulphide, the admission of air, if carried out at all, must be in less quantity than the theoretical amount, as it is essential that oxygen should not pass out of the oxide vessels into the sulphide vessels. Oxygen, passing in even small quantity into the sulphide vessels, causes oxidation of the active sulphide, and if it do not give more serious trouble by driving sulphur forward, will at least impair the life of the material in the vessels. Consequently, where separate sulphide vessels are used it is impossible to completely revivify oxide by admitting a small percentage of air with the gas, though sufficient air may be admitted to considerably extend the life of a vessel.

Use of Weldon Mud.—Weldon mud is now largely used as

* *Journal of Gas Lighting*, vol. lx., p. 945.

a substitute for iron oxide in vessels in the position in the series which we are now considering. The superior absorptive power of this material for sulphuretted hydrogen has already been indicated, and it may be used in a similar manner to that in which oxide is ordinarily worked, but the great advantages it presents are thereby much curtailed. Unlike oxide of iron, Weldon mud is specially fitted for revivification *in situ*, as the pressure thrown by it becomes less as the amount of sulphur absorbed increases. For the reasons given above, however, it is impossible to admit with the gas the full amount of air requisite for the complete revivification of the manganese where "sulphide" vessels follow the Weldon mud. Hence, in practice, when the Weldon mud is used in this position in the series, about 1 per cent. by volume of air is admitted with the gas, and further, complete revivification is brought about by occasionally putting the vessel out of action and blowing a large volume of air through it. On these occasions the heat of the vessel must be closely watched lest the sulphur be fused or the grids burnt at the high temperature sometimes developed by too intense activity of the material undergoing oxidation. The cessation of carbonizing on Sunday at many works furnishes a good opportunity for revivifying Weldon mud in the oxide position in the series without interruption of purification or the slipping of a vessel during working hours. The quantity of moisture in Weldon mud becomes, on an average of the whole mass in the vessel, much reduced by the passage of gas, especially if air is admitted continuously, and the heat further maintained by blowing steam into the lutes. Thus spent Weldon mud should not contain, on an average, over 20 per cent. of moisture, and as it will not have lost, but rather gained slightly in weight, by its use in the purifier, the moisture lost must have been replaced by sulphur. Oxide of iron, on the other hand, will generally be found to have lost weight during use. The use of air with Weldon mud permits of it being completely fouled in vessels in the oxide position without removal from the vessels. In this lies its chief superiority to oxide, though its freedom from organic matter and sawdust permits the extraction of pure sulphur from the spent material, which need not, therefore, be consigned to the sulphuric acid makers, as is the case with spent oxide. This recovery of sulphur, which is of immense importance in the choice of a purifying material, speaks strongly in favour of Weldon mud, and the relative values of sulphur in oxide and in Weldon mud will be again referred to in Chapter xi.

Removal of Carbon Disulphide.—The gas as it leaves the oxide purifiers, arranged after lime vessels as described, is free from carbonic acid and sulphuretted hydrogen. The remaining impurity of importance is carbon disulphide, the amount of which will not, by the processes given, have been greatly reduced by the passage of the gas through the preceding vessels. There will be still present from 30 to 40 grains of this impurity in 100 cubic feet of the otherwise purified gas, and about 6 grains of other sulphur compounds (not sulphuretted hydrogen) in the same volume. In most towns the amount of carbon disulphide and other sulphur compounds that may be present in the distributed gas is limited by statute, and the regulations on this matter imposed on the London gas companies at the present time are quoted later. For the most part those imposed on provincial companies are less stringent, and corporation works are often entirely free from obligation in this respect. The description of the method adopted for the nearly complete removal of carbon disulphide from gas, will apply to all cases where any attempt is made to limit its amount. The 6 grains or so, in 100 cubic feet of gas, of sulphur compounds other than sulphuretted hydrogen or carbon disulphide, are at present allowed to pass forward unchecked, though included in the maximum quantity of sulphur compounds permitted in the gas as distributed.

Preparation and Nature of Sulphided Lime.—The oxides or hydrates of certain metals readily combine with carbonic acid, and calcium hydroxide is used in gas works for the removal of that compound from gas. The chemical analogy between oxygen and sulphur would lead us to infer that certain metallic sulphides or hydrosulphides should possess an affinity for carbon disulphide, and, as a matter of fact, sulphided lime is the material employed in gas works for removing that body from gas. The material for removing carbon disulphide is formed in the vessel in which it is afterwards to do its work, by passing gas containing sulphuretted hydrogen, but free from carbonic acid, through slaked lime, preferably still warm from the slaking. The slaked lime is spread on the grids in the usual manner, the vessel closed, and gas from the outlet of the "carbonate" vessels passed into it. It is essential to the formation and maintenance of a good "sulphide" vessel that the gas passing through it should be free from carbonic acid and oxygen. The sulphided lime so obtained by fouling slaked lime with sulphuretted hydrogen is the active agent employed for removing carbon disulphide from gas. When sulphided, the vessel is put in the series after the oxide purifiers, and as the total amount of impurity to be removed by it is small, it should remain in action for several months without opening. As the lime compound, which is active towards carbon disulphide, is somewhat unstable, and as the affinity between it and the disulphide is not strong, the sulphide vessel is very liable to derangement, and, consequently, it is customary to use two such vessels in series. But even with this precaution care is needed to avoid the admission of air or carbonic acid to the vessels, since their proper working is thereby imperilled, and quantities of carbon bisulphide may be driven off from the material, and the amount of sulphur compounds in the gas increased instead of diminished. Throughout, it must be borne in mind that the oxygen compounds of calcium are more stable than the corresponding sulphur compounds. If the bearing of this fact on the working of sulphide vessels is fully grasped, their so-called fickleness will be found to be unsubstantiated, and a complete acquaintance with the actual facts of each case of defective working of a sulphide vessel will generally at once lead to a simple explanation. The trouble really lies in the facts not being in all cases forthcoming.

The precise composition of the active material of sulphide vessels has long formed a subject of debate for gas chemists. It might reasonably be supposed to be calcium sulphide, more or less moist, from the water used in slaking the lime. It has been shown experimentally that damp calcium sulphide is an absorbent of carbon disulphide, but the absorption is not a complete one, and it seems possible that it may really be due to a decomposition product of calcium sulphide in the presence of water. The published work on the subject does not actually enable us to refute those who contend that damp calcium sulphide is the active material of sulphide vessels, but it may be positively stated that the reaction which takes place in them is not represented by the equation—

$$CaS + CS_2 = CaCS_3,$$

though this is still often used in writings on gas manufacture, to express the action of sulphided lime on carbon disulphide. No such product, as a simple pure calcium thiocarbonate is the result of the reaction that occurs in the purification of gas.

The active material of sulphide vessels has been considered by Lewis T. Wright, among others, to be calcium hydrosulphide, CaS,H_2S or $Ca(SH)_2$. On analogy this seems extremely probable, as it is the sulphur compound of calcium corresponding to calcium hydrate, $Ca(OH)_2$, and might, therefore, reasonably be expected to have an affinity for carbon disulphide, as the hydrate has for carbon dioxide. But, according to V. H. Veley, calcium hydrosulphide is inactive towards carbon disulphide. He formed the salt by passing sulphuretted hydrogen into water containing lime in suspension, and found it to crystallize in acicular needles. It is, however, extremely unstable, and in the presence of air or even inert gases, passes into the hydrated sulphide, thus—

$$Ca(SH)_2 + H_2O = Ca(OH)(SH) + H_2S$$

with evolution of heat. This hydrated sulphide is precipitated when carbon disulphide is passed into a solution of calcium hydrosulphide, sulphuretted hydrogen being evolved, and the absorption of carbon disulphide is said not to commence until such precipitation has taken place. The carbon disulphide, on absorption, throws down crystals of a basic calcium thiocarbonate, which deepen in colour from yellow to red, and dissolve to form a red liquid, which, on evaporation, yields a basic thiocarbonate corresponding to the formula $Ca(OH)_2CaCS_3,7H_2O$. Such a red liquid drains down from the sulphide vessels during their activity, and is removed by siphons. From these data and the fact that the absorption of carbon disulphide is accompanied by evolution of sulphuretted hydrogen, V. H. Veley considers the reactions which take place in the sulphide vessels may probably be represented by the equations—

$$2Ca,SH,OH + CS_2 = Ca(OH)_2CaCS_3 + H_2S$$
$$3CaOHSH + CS_2 + H_2O = 2Ca(OH)_2CaCS_3 + 2H_2S.$$

For the reasons given above, it must not be assumed that these are the reactions that actually occur, and further investigation is still urgently needed. Veley's conclusions have not actually been disproved, though they have been before the gas world for a considerable time,* and his work on the subject does not pretend to be exhaustive. It must be granted that he has made out an excellent case on behalf of calcium hydroxyhydrosulphide (Ca,OH,SH), as the active material of sulphide vessels, and until more conclusive evidence than has at present been brought forward is forthcoming as to the inaccuracy of his deductions, they must be taken as legitimate. It is of little use to attempt a research on the action of sulphide vessels with impure materials and a gas of uncertain composition, and many would-be investigators of the matter have failed through carelessness in this respect. Chemical reactions must be studied, in the first instance, apart from all disturbing influences; when the actions of gases of definite and tolerably simple composition on pure materials have been sufficiently studied, we can pass to the study of more complicated gaseous mixtures, and make due allowance for the presence of disturbing elements. The haphazard and unscientific methods on which many so-called investigations on gas purification have been carried out, is sufficient ground for excluding mention of them from a general review of the subject. Veley's researches, suggested and more or less inspired by A. Vernon Harcourt, form a pointed exception to the general slovenliness of the work on sulphur purification.

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* *Journ. Soc. Chem. Ind.*, 1885, p. 633.

It is a matter of common experience that a sulphide vessel may be inactive through over-fouling of the lime, or what is more common, by formation of the sulphide at a low temperature. The admission of air to the vessel will often bring a sluggish material into an active state, and it has been stated in explanation of this action that the hydrosulphide is oxidized by the air to the above-named active compound. It is certain that air effects a gradual oxidation of the lime sulphide and causes an emission of sulphuretted hydrogen from it; but other gases besides oxygen have the same effect. The calcium thiocarbonate formed by the absorption of carbon disulphide is a rather unstable compound, and is decomposed by carbonic acid with liberation of carbon disulphide. Hence the importance of preventing carbonic acid going forward into the sulphide vessels. The lime for a sulphide vessel should never be fouled at a temperature below 40° F., if possible, as sulphide vessels made below that temperature are sluggish in action, and some have even asserted that different compounds are formed with the lime by the action of sulphuretted hydrogen at comparatively low and comparatively high atmospheric temperatures. Practice shows that sulphide vessels are generally less active in winter than in summer, a fact that is troublesome to the gas engineer, whose greatest make occurs in the former season.

Check Vessels.—In addition to the traces of sulphuretted hydrogen that escape the oxide purifiers, that gas is evolved in small quantity from the sulphide vessels, and it, consequently, becomes necessary to take further steps to effect its complete removal from the gas. Where the regulations imposed on the gasworks are very stringent, and no readily recognisable trace of sulphuretted hydrogen may go out in the distributed gas, it is customary to devote two vessels to this final stage of the purification. These vessels, known as "checks," may contain either lime, iron oxide, or Weldon mud. Ferric oxide would naturally appear to be more economical than lime, as the sulphur is easily recoverable; but, unfortunately, it does not appear to readily absorb the last traces of sulphuretted hydrogen. In many works, however, it is in use, and only where the method adopted for ascertaining the presence of sulphuretted hydrogen is a somewhat exacting one does it give place to lime. Until quite recently lime was invariably used in the check vessels in the Metropolis, and other places where absence of sulphuretted hydrogen was demanded, and the test was a severe one, and it is certainly efficient. Recently, Weldon mud has taken the place of both lime and oxide in the check vessel position in many works, and as it has the sharp action of the former and the economy of the latter, the change appears justifiable. Moreover, the Weldon mud, by the admission of a small percentage (about 0·25 per cent. of the volume of gas) of air at the inlet of the check vessel, can be kept in action almost indefinitely, as it is continuously revivified, whereas lime and oxide require changing tolerably often to ensure the outlet gas being perfectly clean. In fact, the life of a Weldon mud vessel, worked under proper conditions in the check position, is determined by other considerations, such as the periodical cleaning of inlet and outlet pipes, than its efficiency; and as the sulphur taken up is recoverable, it may almost be regarded as an ideal check material. Where lime is used, the pressure thrown by the check vessels increases with the period of their action; but the pressure thrown by Weldon mud rather decreases with length of service. The only objection commonly raised to the use of Weldon mud is the wet and sloppy condition it is apt to assume in the purifier, making its removal a somewhat unpleasant task. The check vessels are usually similar in shape and design to the other purifiers, and the material is shifted and disposed in them similarly. The gas passing from the outlet of the check vessels should not blacken moistened "lead" paper (see Chap. viii.) when allowed to impinge on it from a small orifice for twelve hours, at the rate of 5 cubic feet an hour. If the "lead" paper is properly made, this test is sufficiently severe to ensure the gas distributed being returned as free from sulphuretted hydrogen at the testing stations. Needless to say, the lead paper should be enclosed in a glass or metal case, from which the gas can escape, but which will not admit (possibly foul) air throughout the time of the test.

General View of the Scheme of Purification.—The course of the gas through the purifiers, which are made to subserve four distinct ends, has now been traced. Though one vessel should suffice for each stage of the purification process, it will have been gathered from the above that it is customary for convenience of working and thoroughness to duplicate the vessels, and hence a set of purifiers for the complete scheme of purification indicated above will consist of eight separate vessels. These will be two "carbonate" or lime vessels for the absorption of carbonic acid, two ferric oxide or Weldon mud vessels for the absorption of sulphuretted hydrogen, two vessels of sulphided lime for the absorption of carbon disulphide, and two "check" vessels of lime, ferric oxide, or Weldon mud, for absorbing the last traces of sulphuretted hydrogen. The gas which has passed such a set of purifiers in good working order should be free from sulphuretted hydrogen and carbonic acid, and contain about 10 grains of sulphur and perhaps 1 grain of ammonia per 100 cubic feet, as indicated by the Metropolitan Gas Referees' statutory tests.

Modifications of the foregoing Scheme.—Such a high degree of purity is often not required, and to meet these cases, and those where special working conditions prevail, various other systems of purification have been elaborated. If the principles on which the complete scheme quoted above is based are grasped, the comprehension of most other processes is not difficult. They may be regarded for the most part as modifications of it, in so far as their action is concerned, though many of them are of earlier date and in reality the precursors of the scheme here given. In many provincial works, especially those directly controlled by municipal authorities, no sulphur compounds other than sulphuretted hydrogen are removed from the gas, and hence the sulphide vessels are unnecessary. In some cases no further purification than passage through an oxide vessel is extended to the gas, though in other works passage through lime only is substituted. The choice of material, where sulphuretted hydrogen is the only impurity to be removed, must be determined by the relative prices of ferric oxide and lime at the works, though the usefulness of lime in removing the deleterious carbonic acid must be considered unless the illuminating power of the gas is of no moment. On the other hand, lime has a more direct deteriorating effect on the illuminating power of the gas, as it retains more hydrocarbon vapours than ferric oxide. If the scrubbing surface is insufficient some ammonia will go forward to the purifiers, and red masses of calcium thiocyanate will be found in the lime vessels, as well as the ordinary calcium compounds, and the amount of carbon disulphide in the gas will be perceptibly diminished.

A different order of the usual vessels has been suggested by the patentees of the Weldon mud process of gas purification specially for use with that material. This consists in reversing the usual positions of the oxide and sulphide vessels, so that the latter immediately follow the carbonates. The gas freed from carbonic acid but charged with carbon disulphide, and an amount of sulphuretted hydrogen varying with the extent to which the material in the carbonate vessels is carbonated, passes direct into the previously formed sulphide vessels, where the carbon disulphide is absorbed while the sulphuretted hydrogen passes on to vessels charged with Weldon mud. It is essential to the proper working of this system, that the absorption of carbonic acid in the carbonate vessels shall be complete; and this can only be ensured by putting in a clean lime vessel as soon as the second carbonate shows carbonic acid at the third or fourth tier, and placing the half-fouled vessel first in the series. Gas containing sulphuretted hydrogen, but free from carbonic acid, will not cause derangement in the sulphide vessels, though statements to the contrary are often made. The placing of the sulphide vessels in this position in the series puts them out of risk of disturbance by air or oxygen, which is then admitted to the gas after it has passed the sulphide vessels and is entering the Weldon mud vessels. Thus a more perfect revivification of the Weldon mud can be secured without risk of injury to the sulphided lime. Hood and Salamon recommended the carbonating and sulphiding of lime while hot from slaking, and the maintenance of warmth during the action of the vessels, and claim thereby to obtain a purer carbonate for the spent material, and a more active sulphide vessel. This is in keeping with the well-known experience of gas engineers, that a sulphide vessel formed at a low temperature is inactive, or acts very sluggishly; but the author is not aware that the suggestions of Hood and Salamon have yet been carried out to the full on a working scale.

Where the number of purifying vessels is very limited, and where objectionable odours, on the opening of foul vessels, must be as far as possible avoided, another method of working is very commonly adopted. In this, the use of separate "sulphide" vessels is abolished, and a partially sulphided lime vessel is practically the absorbent material for carbon disulphide. Air or oxygen is admitted to the gas in regulated proportion, either immediately before the first purifier, or at an earlier stage in the course of the gas from the retorts. In the latter case a somewhat varying amount of oxygen is absorbed in the scrubbers, and the exact quantity entering the purifiers with the gas is unknown. This is especially objectionable when pure oxygen is used, hence that is more commonly admitted at the entrance to the purifiers proper. The oxygen, either pure or in air, effects an oxidation of the sulphur compounds of the lime, and sulphur is deposited as such in considerable quantities in the foul lime. The amount of oxygen admitted must not be sufficient to prevent the stability of a certain amount of sulphided lime in the last vessel, or no material will be present for the absorption of carbon disulphide. Consequently, oxygen or air must be used in amount insufficient for the oxidation of the whole of the sulphuretted hydrogen in the gas; that is, oxygen must not be present in the gas at the outlet of the last lime purifier. The air or oxygen may be admitted continuously with the gas in regulated proportion, or, less preferably, admitted in somewhat larger quantity at intervals only. The amount of air admitted with gas containing about 600 grains of sulphuretted hydrogen per 100 cubic feet, should not exceed 2 per cent. by volume, and many engineers prefer to work with less. In fact, ¾ to 1 per cent. of air is the amount more commonly admitted to the lime purifiers, and the unabsorbed sulphuretted hydrogen goes forward to an oxide or Weldon mud vessel. With careful working, and the avoidance of an excess of air or oxygen, this system gives good results, as far as the reduction of sulphur compounds in the gas is concerned, but it is not economical, as a considerable quantity of sulphur is deposited and retained in the lime, instead of all going forward to oxide or Weldon mud, from which it is recoverable. On the other hand, the oxidation maintains the temperature in the vessels, and the spent lime is dry and innocuous, except that on the top tier, which is invariably sloppy. This so-called "rotation" system of gas purification is largely used where the gas works is situated in the heart of a populous district, on account of the unobjectionable character of the spent lime. Whether pure oxygen or air should be used in connection with lime purification is a much-debated question, which turns mainly on the cost of obtaining oxygen and the cost of enrichment. That a small percentage of air admitted before the lime purifiers has not a deteriorating effect on the illuminating power of gas is conceivable, and is, indeed, proved by experience, but that the corresponding amount of oxygen would give a better result is granted by nearly all. Whether the slightly improved result is worth the cost of the pure oxygen is extremely doubtful, though with very impure gas, and with complete revivification of Weldon mud *in situ*, the use of oxygen seems desirable. Many processes have quite recently been devised for producing oxygen at a far cheaper rate than formerly, and if any one of them should prove a commercial success, we may expect a considerable extension of the application of oxygen to gas purification. Up to the present, Brin's process for the production of oxygen is the only one that has been considerably used on gas works. W. A. Valon has especially argued in favour of the use of oxygen in gas purification, and has made out an excellent case for it, but up to the present no such scheme has been adopted in a really large works.

Purification with Gas Liquor.—Very brief reference only can be here made to the schemes for the complete purification of coal gas by washing it with gas liquor or other liquids. There have been very many of these; one of the most important was devised by C. F. Claus, and its essential parts are covered by patents Nos. 7,580, 7,582, 7,584, and 7,585, dated 6th June, 1886. This process has been fully described by C. W. Watts* and C. Hunt.† Briefly, scrubbers packed with broken gannister brick are provided, to allow a space of 8 cubic feet per 1,000 cubic feet of gas passing per day, and spent liquor is led into the last scrubber and passed along the series until, on leaving the first, it is saturated with impurities. The carbonic acid and sulphuretted hydrogen are driven off from the liquor by heating it, while the ammonia is retained by scrubbing. Ammonia driven off from the liquor enters the second scrubber in order to remove a further quantity of acid impurities from the gas, while the spent liquor is returned to the last. The excess liquor is withdrawn at intervals. One of the sulphur compounds of ammonium, probably the disulphide, $(NH_4)_2S_2$, has an affinity for carbon disulphide, and the sulphur compounds in the gas can be reduced to 20 grains per 100 cubic feet by the systematic use of Claus' system. The process has been tried on a tolerably extensive scale, with fairly satisfactory results, but it has not been commonly adopted. With regard to this and other schemes for the purification of gas by liquor, it may be pointed out that Lewis T. Wright has argued for and against liquor purification on theoretical grounds, from the relative amounts of acid and alkaline constituents of gas liquor, and the proportions in which they are expelled from the liquor on moderate heating.‡ His arguments are based on the combining equivalents of ammonia and carbonic acid and sulphuretted hydrogen, and the relative proportions of these bodies in the crude gas. He concludes that the expenditure of heat in raising the temperature of sufficient liquor for the purification of the gas from a ton of coal, to that required for the expulsion of a large proportion of its acid constituents, is not prohibitive to the success of a scheme of liquor purification, and it is difficult to see precisely why such a process has not more generally succeeded.

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* *Journ. Soc. Chem. Ind.*, 1887, p. 25.

† *Journ. of Gas Lighting*, 1886, p. 1181.

‡ *Journ. of Gas Lighting*, 1886, pp. 280, 329, 373, and 511.

CHAPTER IV.

CARBURETTED WATER GAS.

Carburetted Water Gas.—The mixture consisting essentially of hydrogen and carbonic oxide, obtained by the decomposition of steam by incandescent carbonaceous material, is commonly known as water gas. This gas burns with a non-luminous flame, and without admixture is useless for lighting purposes, except where it is used to raise refractory earthy films to incandescence, though even for this purpose it has not hitherto proved satisfactory, and has been discarded in favour of gas containing an admixture of hydrocarbons. But where cannel and rich bituminous coals are scarce, and anthracite or coke and mineral oil are plentiful, a mixture of water gas and oil gas has been freely used in place of coal gas. The proportion of oil gas to water gas may be varied according to the illuminating power required of the mixture, but it is not customary to make the latter of lower than 20 candle power, and more often it is nearer 30. This is, perhaps, owing to the fact that where carburetted water gas is distributed without, or with little admixture of coal gas, oil is cheap, and a high candle-power gas can be manufactured at a very low cost. It has been found convenient and economical to produce the oil gas and water gas simultaneously in parts of the same plant, and to allow the water gas to mix with the oil gas immediately the latter is formed. The subjection of the mixture to a high temperature with a view to ensure the permanency of the oil gas generally follows. It is to gas made under these conditions that the term carburetted water gas is generally applied. Where oil and anthracite are abundant, the manufacture of carburetted water gas is very considerable. It has been estimated that two-thirds of all the gas made in North America at the present day is of this variety. A treatise on illuminating gas, if in any degree pretending to comprehensiveness, must, on this account alone, cover the production of carburetted water gas, but the introduction recently of the manufacture on an extensive scale into this and other European countries gives the subject still greater importance. The scarcity of good cannel coal and the rapid exhaustion of our home supplies, together with the cheapness of mineral oil and the increasing facilities for its transport, have led to the introduction of oil as an enriching material into this country, and the system of incorporating oil gas with water gas, which was devised and elaborated in the United States, has naturally been adopted, in the first instance, in preference to new and untried methods of utilizing oil. The use of large quantities of oil in place of cannel has depreciated the value of the latter, and the question—which is the cheaper enriching material?—must be decided according to their cost at the works at the prevailing market prices. The works which can avail itself of either or both, at will, is distinctly in the best position, and can take advantage of fluctuations in the prices of either. Nevertheless, it may be remembered that cannel would now be at prohibitive prices in most parts of England but for the extensive use of oil in several large gas works. The manufacture of carburetted water gas is generally supposed to give a higher duty for the oil than the manufacture of oil gas, and American gas engineers favour this opinion, which is, however, somewhat discredited in this country.

The varieties of plant proposed for the manufacture of water gas are far too numerous for mention here, but they may at the outset be classed under two heads—(1) Forms in which the requisite temperature of the carbonaceous matter used for reacting on the steam to produce gas is secured and maintained by the cessation of gas making at regular intervals, during which a blast of air is passed through the carbon till it is in a state of vivid incandescence; (2) forms in which fuel is used to maintain continuously the temperature of a mass of carbonaceous material sufficiently high for the decomposition of steam, which is admitted uninterruptedly to form water gas.

The first system is commonly known as the **intermittent**, and the second as the **continuous**. The second entails the use of a separate chamber for the carbon used in the formation of gas to that for the fuel used in maintaining the temperature, and, consequently, the heat must pass *through* a wall of refractory material, as in the case of the ordinary coal-gas retorts, with inevitable loss. In this variety of plant, the heat is almost invariably applied externally only to what is virtually a retort, consequently the surface from which radiation can take place is very great in comparison with the mass of carbon raised to gas-making temperature, and the loss of heat therefrom is considerable. These objections, of course, apply equally to the ordinary methods of raising coal to the temperature of gasification; but in the manufacture of coal gas no other system is feasible. In the production of water gas there is the first system as an alternative, and it is not surprising, therefore, that the second or continuous process of gas producing has been commonly discarded in extensive water-gas installations. The Gwynne-Harris and Allen-Harris, as well as other continuous water-gas systems, have been worked on a practical scale in the United States, but are not of sufficient interest to require detailed description here.

Intermittent System.—The intermittent processes for the production and carburetting of water gas are many, but few are extensively worked at the present day. They may be regarded as derived by successive modifications from the Tessié du Motay system, and to have culminated, for practical purposes, in the modern forms of the Lowe plant, which is that most extensively adopted in this country and in the United States. Before considering the details of the plant, it will be convenient to state briefly the reactions involved in the production of water gas.

Action of Carbon on Water Vapour.—The reactions that take place between incandescent carbon and water vapour are determined, primarily, by the temperature, and the relative masses of the reacting bodies. Other conditions are either dependent on these or of secondary importance. The reactions are best studied, in the first instance, by assuming that pure carbon and water vapour only are present. At 600° C., carbon decomposes water vapour appreciably in accordance with the equation:—

$$C + 2H_2O = CO_2 + 2H_2.$$

At a slightly higher temperature a small quantity of carbon monoxide is formed, and at about 1,000° C. the products of the action of excess of carbon on steam are appreciably carbon monoxide and hydrogen, which may conceivably be formed according to the equation:—

$$C + H_2O = CO + H_2.$$

As a matter of fact the reaction never appears to be quite complete, and a small percentage of carbon dioxide remains in the product. This is not surprising, when we recall what happens when carbon dioxide is brought in contact with excess of carbon. At 600° C. practically no reaction takes place; but as the temperature rises an increasing amount of carbon monoxide is found in the product, until at 1,000° C. not more than 3 per cent. of carbon dioxide remains, while even at a higher temperature nearly 1 per cent. persists. Another reaction which has to be considered is that between water vapour and carbon monoxide. When any action takes place it is in accordance with the equation:—

$$CO + H_2O = CO_2 + H_2.$$

At 1,000°, however, this does not extend to the whole mass, though the carbonic acid formed increases with an increase in the amount of water vapour. Under conditions which may occur in a water-gas generator any of these reactions may take place. As the ideal water gas should contain a minimum amount of carbon dioxide (and, consequently, a maximum amount of carbon monoxide), a study of these reactions will indicate the most favourable conditions for the production of this ideal gas.

Conditions required for Producing Water Gas.—The temperature of the body of incandescent carbon should not be below 1,000° C.; but as a portion of it is necessarily cooled by the entering steam, some carbon dioxide remains, and must be got rid of through the conversion of carbon dioxide to carbon monoxide by carbon, at a temperature of 1,000°, such conversion being effected by passing the gas through a further layer of carbon at that temperature. Hence the necessity of a bed of carbonaceous material sufficiently deep for the gas first formed to pass through a layer of carbon at a temperature of at least 1,000° C. before it passes from the generator. Further, the carbon must be in excess, in order that no steam may pass out from the generator with the gas, as there is a risk of it reacting on the carbon monoxide formed to produce carbon dioxide, in accordance with the last equation given. An amount of steam over and above that which would be decomposed by the incandescent carbon in passing through it would generally considerably reduce the temperature of the carbon in a short time, and thus indirectly also affect the quality of the gas. The first points required in a water-gas generator for the economical production of good gas are, therefore, the means of producing and maintaining during the making of gas a high temperature in the generator, a sufficient depth of fuel, and the regulation of the amount of steam admitted. How these requirements are attained in one fairly typical plant may be seen from the description of it on p. 126. Up to this point purity of materials has been assumed, but it is, of course, in practice impossible to use pure carbon. Pennsylvanian anthracite is probably the purest carbon that is used on a large scale for the purpose, and is admittedly unsurpassed for yield and purity of gas. It stands to reason that, as it is carbon which reacts with steam to form water gas, the efficiency of a carbonaceous material for the manufacture must, *cæteris paribus*, depend on the carbon content of the material, or, in other words, the greatest yield of gas is obtained from that material which weight for weight contains most carbon. This fact is indisputable and cannot be evaded, though its truth may be obscured in certain cases by inattention to details of working. Where gas coke is used for the production of water gas, it should, therefore, be as free as possible from non-carbonaceous matter, or, speaking broadly, it should leave little ash on combustion. The density of the material and its degree of division are of great importance indirectly. The more dense a material, the less depth required in the generator for a given current of steam is a broad general rule, dependent on the fact that it is a given mass and not a given volume of carbon that decomposes a given mass of steam. Hence a considerably greater depth of gas coke than of anthracite is required in a generator for the same amount of steam admitted, or, practically, generators intended to use coke should be deeper than those intended to use anthracite, on account of the difference in the densities of these materials. Further, the steam should flow equally through the carbonaceous matter, a consummation only to be attained by the interstices between the lumps of material being of approximately equal dimensions. They are so only when the lumps of material are of fairly uniform size, hence the anthracite or coke used must be broken or screened accordingly. With coke attention to this point is particularly necessary, lest the steam make its way through the mass by a few passages only, and the apparatus have a decreased efficiency. This state of things is aggravated by the readiness with which the ash of many cokes fluxes; the masses of clinker hinder the proper diffusion of the steam. In practice it is found that gas coke, in pieces from 2 to 4 inches diameter, screened from all dust, answers well. Occasional raking and pricking of the mass tends to break up lumps and secure the equable diffusion of the steam in its passage through it. The working of a generator may be very accurately gauged by the percentage of carbon dioxide in the produced gas. This must be low; 3 per cent. is a sufficient maximum to allow with coke in the generator. It is evident that carbon dioxide not only means so much incombustible gas in the product, but also means a loss of the equivalent quantity of the combustible carbon monoxide. When water gas is to be used for illuminating purposes the carbon dioxide must be removed, as it detracts most markedly the photogenic value of illuminating gases. Economy, both in the production and in purification of water gas, can, therefore, only be secured by keeping the percentage of carbonic acid low. On the other hand, the volume of gas made per hour must be as high as possible, or the highest duty is not obtained from the plant. Therefore, it is well to find by trial the greatest amount of carbonic acid that can be allowed in the gas without the outlay involved by its presence therein, being in excess of the gain from the increased volume of gas made. This maximum amount of carbonic acid permissible having been ascertained, the amount of steam admitted to the generator should be as much as possible, always provided the said amount of carbonic acid is not exceeded. The amount of carbonic acid in the gas should be ascertained by tests made at regular intervals, according to one of the methods described later. 3 per cent. may be taken as a maximum when the gas is to be used for illuminating; a greater amount involves a ruinous outlay on purification. Of course these remarks on the admission of steam and the percentage of carbonic acid in the gas assume that the fire is kept in good condition—*i.e.*, at the proper temperature, free from ash, and the fuel in a proper state of division. When this is the case, it will be found that the amount of steam admitted can be kept nearly constant when once the proper quantity has been ascertained. An abnormal percentage of carbonic acid in the gas will then indicate that the fire is not in a proper state of efficiency, and attention should at once be directed to it.

Where carburetted water gas is being manufactured for illuminating purposes, the process of carburetting follows immediately on the production of the crude water gas. In the earlier forms of apparatus, oil was run into the generator while gas was being made, and was more or less vaporized by the incandescent fuel; and the vapours were carried away by the water gas, and were more completely incorporated with it in a subsequent chamber, known as the fixing chamber or superheater. This method of vaporizing the oil had many obvious faults. The top layer of the fuel in the generator varied in temperature according to the lapse of time since fresh fuel was added to it, consequently, much of the oil was at one time lost through imperfect vaporization, and at another time suffered from overheating and consequently deposited carbon. Especially was the method inapplicable to heavy distillates and crude oils, such as are now largely used for carburetting water gas. The need of vaporizing the oil at a definite and uniform temperature having been demonstrated, the introduction of a chamber which could be kept at the proper heat for the purpose, into most modern water-gas plants, followed as a matter of course. In some, heat is applied to the chamber externally, in others internally, between the intervals of gas making, while others make use of both methods in succession. By whatever plan it is carried out, the oil must be completely converted to vapour, and carried away as such by the water gas, and, on the other hand, the heat applied must be short of that at which carbon is deposited on the surfaces of the chamber. The system which provides for the gradual heating of the oil, and in a measure fractionates it, will, *cæteris paribus*, be productive of the best results.

The oil vapours mingled with the water gas are, at this stage of the process, only to a limited extent permanent gases at ordinary temperatures, and if the mixture was not subjected to further treatment, it would be totally unfit for distribution. It is found that, by subjecting the mixture for a short time to a high temperature, the less stable vapours are broken up and converted into more permanent gases. Therefore, most plants have either an extended vaporizing chamber, which, by virtue of its length, keeps the vaporized oil at a high temperature during its passage through its posterior portion, or a separate superheating chamber into which the mixture of water gas and vaporized oil passes, and in which it is subjected to a high temperature. The latter plan has advantages over the former, inasmuch as it allows of the regulation of the temperature of one chamber independently of the other. The superheating chamber must not be hot enough to separate carbon from the oil vapours, but if it does not nearly approach the temperature at which such separation occurs, the gas will suffer from the want of permanently gaseous hydrocarbons. The means by which the heat of the vaporizing and superheating vessels is maintained, differ slightly in different descriptions of plant, but must admit of easy control of the temperature of either vessel. The regulation of the temperature affords scope for the expenditure of much care, and should be in the hands of a man accustomed to the plant and the description of oil used. When the gas leaves the superheater it is ready for the ordinary processes of condensing, scrubbing, and purifying, though these are often conducted in different order, and in differently-constructed apparatus to the similar processes in coal-gas manufacture.

Lowe Plant.—The improved Lowe plant, for the manufacture of carburetted water gas, is extensively used in the United States, and, with slight modifications, has been adopted in London works. It is not protected by letters patent in this country, though many improvements and modifications of the original form have recently been patented. Being worked on the intermittent system, two sets of apparatus practically form the smallest number that can be operated. They may vary in dimensions, but those in use in London have a capacity equivalent to a nominal make of half a million cubic feet of gas per set per twenty-four hours, and when gas of not less than 24 candle power is made, this nominal make is below the actual producing power of a set. This size of plant is a convenient one, and may be taken as typical of the system. Two sets capable of making one million cubic feet of gas of about 25 candle power with the greatest ease, and with the highest duty per unit of oil and fuel will have dimensions, and be worked somewhat as follows:—

General View of the Plant.—The **generator** shell will be about 10 feet in diameter, and have a height of about 18 feet from the base to the lid seating, the fire bars being about 4 feet from the bottom. There will be a large door in the shell below the bars, for the removal of ash, and the ash pan will, of course, contain water, the vapour of which will serve to cool the bars. The shell will be lined internally with firebrick, which may leave the interior still of circular section, or, preferably, according to some authorities, the bricks should be placed so as to give a polygonal cross-section. Four doors are placed at equal distances apart, about 4 feet above the level of the fire bars, for use when cleaning the fire. The upper part of the generator should be the frustrum of a cone, the lid, about 2 feet in diameter, being on a faced seating, and pivoted at one side, so as to revolve horizontally for opening and closing the generator for feeding purposes. When shut, the lid is kept tight on the seating by a screw turning on a cross-bar, and actuated by a T-handle. Near the top of the generator is the gas-outlet pipe, which leads into the next vessel, of about the same height as the generator, but packed with small bricks arranged chequerwise. In the top of this vessel, which is termed the **carburettor**, is an inlet pipe for heated oil, which is dispersed, when admitted to the vessel, by a cone on to which it plays. The outlet of the carburettor is near the bottom, and leads into the next vessel, known as the **superheater**. This is about 6 feet higher than the preceding vessels, but is, like the carburettor, packed with bricks chequerwise. From the side of this vessel, near its top, proceeds the gas-outlet pipe, leading down to a small vessel which acts as a **tar extractor**, and in which the end of the pipe is sealed with tar. In this vertical pipe is placed a smaller pipe, through which the oil passes on its way to the carburettor, being heated by the hot gas, and, consequently, entering the carburettor in a partially vaporized state. On the top of the superheater is the seating for a heavy valve, actuated by levers from below, and opening under the mouth of a shaft. This valve is shut during the process of gas making, but open during the blowing-up process, to allow the products of the combustion of the generator gas to pass up the shaft, and so out of the building. From the tar extractor the gas passes into a **scrubber** about 6 feet in diameter and about 20 feet high, filled with bundles of wood, down which water trickles. Thence it passes into a **tubular condenser**, through which cold water circulates, and thence to the gasholder and purifiers.

To the bottom of the generator there enters also a blast pipe, and blast pipes are also attached to the carburettor and superheater. The blast is generally obtained from fans running at high speed, but there is no reason why other blowing engines should not be used. The pressure of air required is not great; sufficient to support a column of water 12 to 15 inches high is ample.

Outline of the Process.—Fig. 25 shows the more important details of the plant. Supposing that there is a clean fire in the generator, A, at a dull red heat, and it is desired to make gas, the process would be, roughly, as follows:—Air at about 13 inches of water pressure would be admitted to the bottom of the generator by the blast pipe, *b*, and, passing through the fuel, would form producer gas, and the reaction being exothermic, the temperature of the fuel will gradually rise. The producer gas passes out of the generator by the pipe, *c*, into the carburettor, C, where it meets a blast of air from the pipe, *b′*, and is partially consumed, the heat of combustion raising the temperature of the chequer bricks in the vessel. The unconsumed gas and the products of combustion of the consumed gas pass by the pipe, *c′*, into the superheater, S, where a further blast of air enters by the pipe, *b″*, and completely consumes the producer gas, raising by the combustion the temperature of the chequer bricks in the vessel. The products of combustion pass out at the open stack valve, V, and up the shaft, D. When this process has continued for five to ten minutes, according to the heat of the fuel and the vessels at the commencement, and the fuel in the generator is at a bright heat of about 1,100° C., steam is admitted instead of air to the generator by the pipe, *s*, and the blast is shut off from the other vessels, and the stack valve, V, closed. Water gas is formed in the generator, A, and passes into the carburettor, C. At the same time the tap, *e*, on the oil pipe, *f*, is turned on, and heated oil slowly pumped into the carburettor. The water gas meets the spray of oil, which is gradually gasified, and carried on by the stream of water gas into the superheater, S, where it is converted into a permanent gas, and the mixed oil and water gas leaving this vessel has a fairly uniform composition. The mixed gas passes by the pipes, *g* and *h*, the latter of which contains the oil heater, *k*, into the seal, T, the pipe, *h*, dipping under the tar in the bottom of the vessel. From this it passes by the pipe, *m*, into the scrubber and condenser, and thence out of the house. The process is continued as long as the generator fuel is sufficiently high in temperature to produce good water gas; when it falls below the necessary temperature, the steam and oil are shut off, the blast

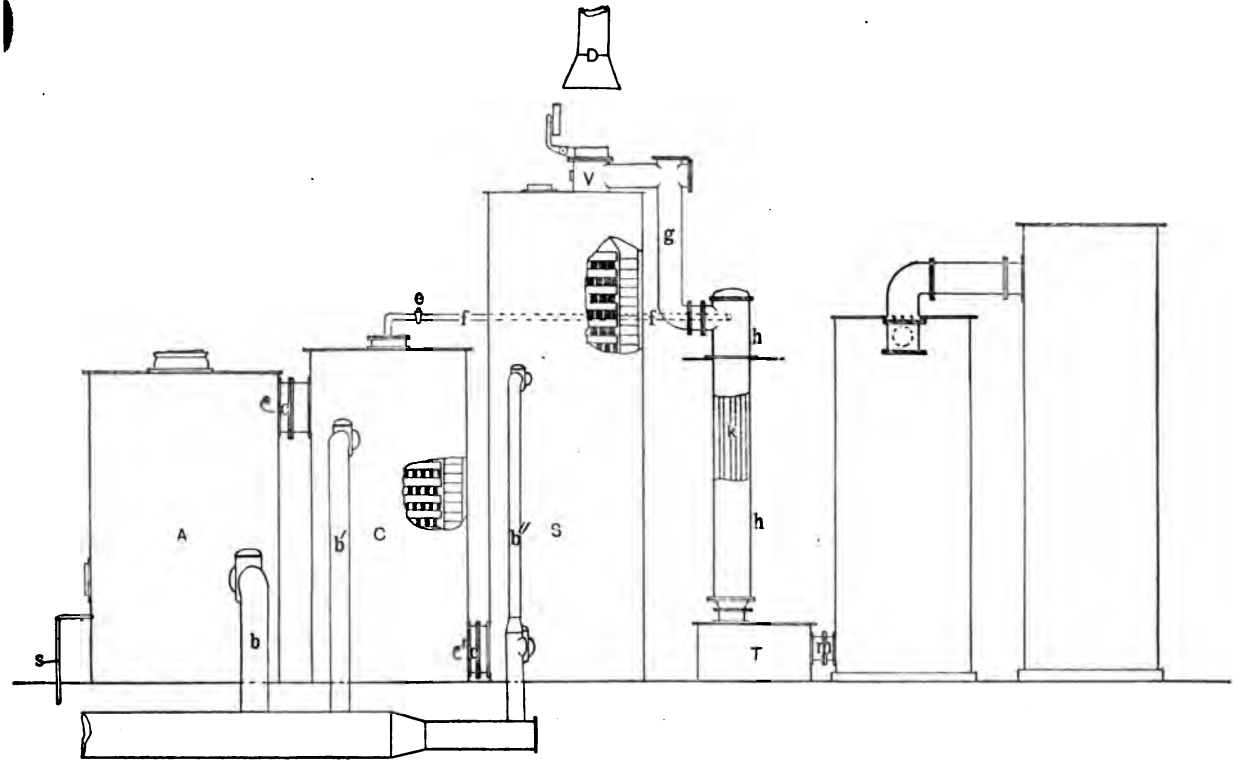

Fig. 25.—Improved Lowe carburetted water-gas plant.

A, Generator; *b*, *b′*, *b″*, blast pipes; *c*, pipe leading from generator to carburettor; C, carburettor; *c′*, pipe leading to superheater; S, superheater; V, stack valve; D, shaft; *e*, tap on oil pipe; *f*, oil pipe; *g*, *h*, mixed gas pipes; *k*, oil heater; T, seal; *m*, pipe leading to scrubbers.

turned on, and the stack valve, V, opened, and the process of getting up the heat carried out again in precisely the manner described above. In practice it is found that the periods of gas making and blowing up may conveniently be equal, and if two sets are working, gas may be made in each alternately, and thus the make kept fairly constant throughout. In this manner one scrubber and one condenser will serve for the two sets, the gas from each in turn passing into them. Also, the blast changes in turn from one set to the other, and thus may be kept constant; a very convenient arrangement when a fan supplies it.

Management of Plant.—The steam used for producing gas must be superheated, or, at high pressure, say 130 lbs. per square inch. If it is at all damp, it readily condenses on the fuel with which it first comes in contact, and reduces the lower layer in the generator to an inactive state, from which it cannot be again raised to incandescence by the blast. This congealing of the lower layer of fuel always takes place to a certain extent in the ordinary generator, but it is much aggravated by the employment of damp steam. It may be almost entirely avoided by arranging the plant, so that the steam may periodically be admitted at the top of the generator, and the gas produced taken off at the bottom. A plant so arranged is now being exploited by Humphreys and Glasgow in this country. The amount of steam admitted must, as already indicated, be regulated by the amount of carbonic acid in the gas made. The gas may conveniently be tested by samples taken in some simple gas burette from a cock on the generator lid. The percentage of carbonic acid in the gas increases as the run proceeds, as may readily be seen by taking off more than one sample during the run. Thus, if the run or period of gas making lasts five minutes, a generator in good working order, with gas coke as fuel, and dry steam for decomposition, should produce gas which, on testing, gives results somewhat as follows:—The gas is allowed to blow through a burette for one minute, when the burette is closed and removed, and another substituted. Then the gas in the burette taken off

At the end of the first minute should contain about 0·3 per cent. of carbonic acid.
" " second " " " 0·6 " "
" " third " " " 1·4 " "
" " fourth " " " 2·6 " "
" " fifth " " " 4·2 " "

These amounts may sometimes be exceeded, especially when the fire is shortly to be cleaned, but the average amount of carbonic acid in the gas made during the run should not be much over 3 per cent. For tests to control the working of the apparatus, it will suffice to take off two samples of gas, one midway through the run, and the other at the end of the run. Then with a six minutes' make, the following results may be considered satisfactory. Sample taken off

At the end of the third minute contained 2·2 per cent. of carbonic acid.
,, ,, sixth ,, ,, 5·8 ,, ,,

If fresh fuel is put on at regular intervals, and the fire cleaned at regular intervals, a time not immediately after the first operation, nor shortly before the second, may legitimately be chosen for taking the samples by which the working of the apparatus is to be judged. Samples should be taken from each generator and tested twice or thrice during the twenty-four hours.

The fuel should be fed into the generator at regular and tolerably frequent intervals. A hopper with loose conical-shaped bottom, which is let down into the generator to spread the fuel by means of a chain winding on a wheel and axle on the top of the hopper, is useful for feeding the generator. It may conveniently hold about 5 cwt. of coke, and is mounted on wheels for ready transference from the coke store or elevator to the generators. The fuel must be put on as soon as a run ceases, before turning on the blast. There is no danger in opening the generator lid at this time, when the apparatus is at a proper working heat; but when starting a set which has been let down, a slow fire should be put in a day or so beforehand, and before the blast is used, the generator should be filled to the top with fuel. After the blast is started, the generator should not be again opened until the apparatus is at a working heat. By this means explosions which shake the firebrick lining may be avoided. It will generally be found convenient in working, to add the fuel at intervals of about two hours; care must be taken that the bed of fuel in the generator is kept at a high level.

Sight cocks should be provided, one on the generator lid, one about 5 feet from the bottom of the carburettor, another in a similar position on the superheater, and one on the superheater about 5 feet above the working-stage, which is on a level with the tops of the generator and carburettor. By using these cocks the temperature of the vessels may be judged roughly by practised eyesight. The glass or talc requires cleaning from tarry matter occasionally, and should of course be protected from the heat by keeping the cock closed until it is necessary to view the heats. Beside the upper sight-cock on the superheater should be a small pet-cock, through which a little gas may be blown off during making. By allowing the gas to impinge on a piece of white paper a rough idea of the working of the apparatus is afforded. The stain on the paper should not be very tarry in nature, nor should it consist of dry carbon particles. The first kind of stain shows that the heats are too low, the second that they are too high to yield the best results obtainable from the oil.

In the pipe leading down from the superheater to the seal is contained the oil heater. This consists of a tube or series of tubes through which the oil passes on its way to the carburettor. Many patterns have been tried, and some designs patented, but it has been found that heating surface must be sacrificed to gain durability; the multitubular heater, which exposes a large surface to the hot gas, rapidly beginning to leak at the joints. Whatever form of oil heater is adopted spare ones should be kept in readiness, so that as soon as the one in use shows signs of leaking it may rapidly be replaced. Spare doors, valves, and seatings for the remainder of the plant should likewise be kept in readiness, to minimise the delay in case any of those in use crack. The scrubber is generally packed with bundles made up with lengths of inch-square deals with intervening spaces about an inch wide, the arrangement being as far as possible chequerwise. The condenser generally used consists of a cylinder closely packed with 2-inch tubes; the joints must be carefully made to prevent leakage of the condensing water, and consequent dilution of the tar. The tar overflows from the seal into the tar well. The condensation of the gas by this apparatus is effected very suddenly, and in a manner quite contrary to the principles followed in coal gas condensation in this country. It appears extremely probable that were the atmospheric condenser used for carburetted water gas, the illuminating power would be higher, and less liable to decrement on storage of the gas than that of gas condensed by the method adopted at present. The tubular water condenser is, however, economical of space, and can easily be included in the building containing the gas-making plant. Siphons must be placed at the lowest points of the mains leading to the gasholder and purifiers, to draw off water and light oil thrown down after the condensers. Light oil is also slowly deposited in the holder when the gas is stored without admixture of poorer gas. The character of the light oil thrown down from crude carburetted water gas is very similar to that of the lighter distillates from oil tar, and will be briefly described in Chapter xi.

Purification of Carburetted Water Gas.—To properly treat of the purification of carburetted water gas, the nature and average amount of the impurities present in it must be stated at the outset. Gas made from good gas coke, and under proper manufacturing conditions, should, as stated above, contain a little less than 3 per cent. of carbonic acid. It will also contain from 90 to 150 grains of sulphuretted hydrogen per 100 cubic feet, or 0·15 to 0·25 per cent. by volume. It will be practically free from ammonia, and carbon disulphide and sulphur compounds other than sulphuretted hydrogen are present in trifling quantities only, the amount never to my knowledge exceeding 10 grains of sulphur per 100 cubic feet. Hence, purification from carbonic acid and sulphuretted hydrogen only is needed. The amount of carbonic acid is such that a lime purifier becomes exhausted when a volume of water gas less than half the volume of coal gas which it would take has passed through it. Hence the purifying vessels must be large, and arrangements must be made for frequently recharging the "carbonates." Two "carbonate" and two "oxide" vessels in series should suffice for the complete purification of water gas; but a check vessel would generally be added to prevent the possibility of a trace of sulphuretted hydrogen escaping. The dark stain on lead papers sometimes caused by deposition of oily particles from rich gas must not be mistaken for the sulphide mark, as it would not be evident after the gas had been admixed with a large quantity of low quality gas. The lime in the first vessel especially absorbs a large amount of oil, and this and the toxic properties of carbonic oxide render the work of emptying the vessels unpleasant and unhealthy. Nevertheless, the purification of water gas is, from the absence of "sulphur compounds," far simpler than that of coal gas. The quantity of carbonic acid in the gas entering the purifiers may be estimated as often as desired, by a standardized solution of barium hydrate applied to a measured volume of gas taken from the inlet pipe, in the manner described in Chapter viii. Or the test may be made on the gas at the outlet of the exhauster or inlet of the gasholder. The gas going to the testing apparatus should pass through an oxide purifier to remove the sulphuretted hydrogen; and in order to prevent the gas in the service being stagnant, two or three small burners should be fixed to the service close to the inlet to the testing bottle, and the gas should be burning at them continuously. In most cases it will be necessary to have a governor to reduce the gas pressure to 2 or 3 inches of water on the service between the main and the purifier. Otherwise, the varying pressure will cause the solution in the testing bottles to be sucked up the inlet tube at intervals, and a great pressure renders a deep lute to the purifier a necessity. By the use of this test, which may be arranged to run for from an hour to twenty-four hours, the average amount of carbonic acid in the gas from several sets for a given short period, or throughout the day, may be readily ascertained, and any improper working of the plant remedied before it is indicated by the rapid fouling of the lime purifiers. It is seldom necessary to estimate the sulphuretted hydrogen in water gas; but if desired it may be done on the same supply as the continuous carbonic acid test, by slipping the oxide purifier and using one of the methods of estimation given in Chapter viii.

Composition.—The composition of carburetted water gas as made by the Lowe process may now be considered. The impurities have been enumerated above, and, therefore, may be omitted here, the gas now considered having undergone the usual process of purification for the complete removal of carbonic acid and sulphuretted hydrogen. This process will have deprived the crude gas of some of the readily condensable hydrocarbon vapours originally present in it. Carburetted water gas being virtually a mixture of oil gas and water gas, it will at once be evident that its composition must vary according to the proportions of its two component gases, and, consequently, according to the amount of oil used per run in the manufacturing plant. In the plant for the nominal make of half a million cubic feet of gas per set per day, it has been found that the greatest economy of oil accords with the production of gas of an illuminating power of about 26 candles. The chief constituents will be present in this gas in about the following proportions:—

	Per cent. by volume.
Hydrogen, ...	34·0
Methane, ...	15·0
Hydrocarbons absorbable by fuming sulphuric acid,	12·5
Carbonic oxide, ...	33·0

In addition there will be a small amount, ranging from 0·5 to 5·0 per cent. of nitrogen, and a trace of oxygen. The specific gravity of this gas will be about 0·62 (air = 1). In some analyses, hydrocarbons not absorbable by bromine or other reagents figure, and are denominated paraffins. They are thrown down by the application of extreme cold or pressure to the gas; they do not often amount to 1 per cent. of the total volume. The hydrocarbons absorbed are seldom differentiated in analyses, and, consequently, their nature is little known; hence the degree of absorption is but a poor criterion of the illuminating power of a gas, except for comparative purposes in the case of samples produced under precisely identical conditions of temperature and apparatus. With the Lowe plant as usually worked with Russian solar oil, a large proportion of the hydrocarbons are of the aromatic series; but with the older plants, such as the Tessié du Motay, where the breaking up of the oil is less complete, unsaturated fatty hydrocarbons predominate.

Other Plants.—Of the other plants for the manufacture of carburetted water gas, few have attained to any degree of importance. The **Springer** resembles the Lowe in its general principles, but the blast enters at the bottom of the generator, and the steam enters at the top and passes downwards. The hot water-gas heats the oil in very similar fashion, but the superheater is placed above the generator, instead of alongside it. For the apparatus, a saving of ground space for the erection of the plant, as compared with the Lowe, may legitimately be claimed, but this advantage has evidently not been generally thought sufficiently tempting to justify preference being given to the Springer. More recently a modified form of Lowe plant, known as the Merrifield-Westcott-Pearson apparatus, in which the superheater is above the carburettor, has been introduced here, as also in the United States and Canada. The **Van Steenburg** plant does not possess separate superheating chambers, but the oil being run in some distance down the generator, the layer of incandescent fuel above is relied upon to crack it and fix the vapours. This small superheating surface renders the plant unfit for producing a permanent gas from oils of high boiling points. Several attempts have been made to reduce the amount of carbon monoxide in carburetted water gas to a minimum. Where the gas is to be used undiluted with coal gas, it may be granted that the removal of this poisonous constituent is a desirable consummation, but where the gas is used in small proportion to enhance the illuminating power of common coal gas, it appears undesirable to complicate the process and the apparatus for its production by taking elaborate care to remove the carbonic oxide. The reduction of the carbon monoxide to one half the volume in ordinary carburetted water gas, is effected in a plant lately devised in this country—by means of the alternate reduction of iron oxide by producer gas, and its oxidation by steam with liberation of hydrogen, which is allowed to mingle with water gas produced in the ordinary way. Except in so far as hydrogen is a more desirable diluent than carbon monoxide for the development of the illuminating power of admixed gaseous hydrocarbons, no appreciable good can result from the use of this gas in place of the ordinary water gas in works where the enrichment of coal gas only is aimed at. Coal gas contains about 7 per cent. of carbon monoxide; enriched with carburetted water gas to 17 candles, analyses show that it contains about 11 per cent. of that constituent; the same enrichment with the Lewes gas, which, with an illuminating power of 20 candles, is stated to contain 15 per cent. of carbonic oxide, would give a gas containing not less than 9 per cent. of that component. The difference in the toxic action of the gases enriched by the two enriching gases, would be inappreciable, and is certainly not sufficient to justify discarding the simple generator for a triple-chambered one. Where carburetted water gas is distributed as such, it is desirable to reduce the carbon monoxide to about 10 per cent., if the cost of reduction is not prohibitive by reason of complication of plant or less economical working. If a more highly-hydrogenized gas than water gas can be produced at an equal or less price than the latter, the diminution of carbonic oxide should speak in favour of the former. According to O. Wyss,* 0·1 per cent. of water gas (uncarburetted) renders the air of a room injurious to health, while 1·0 per cent. makes it fatal to warm-blooded animals. This lethal quantity would be reached in a room 9 feet high and 13 feet square in one hour, by allowing pure water gas to stream from an ordinary gas tap, according to the same authority, but this really requires the gas tap to deliver 15 cubic feet per hour. With carburetted water gas, the quantity required to render the air of a room lethal would be much greater (supposing the toxic action to be entirely due to carbonic oxide), and a burner suited for the economical consumption of 25 candle gas would have to deliver such gas into a room for about ten hours before a lethal atmosphere would be produced, and this on the assumption that there was no interchange of air between the room and the atmosphere outside. Though undoubtedly slight leaks of carburetted water gas would cause great injury to the health of the inmates of a house in which they occurred, no fatal results need be anticipated from any ordinary mishap leading to an escape of gas for a few hours, and the penetrating odour of the gas would lead to the detection of leaks quite as readily as with coal gas. The supply of pure water gas to houses for heating purposes, and lighting on the incandescent system, would be much more dangerous, even if the gas were rendered odorous. The danger of accidental poisoning from carburetted water gas is almost confined to the works where it is made; there ample time must be allowed for accumulations of the gas to be dispersed before a man proceeds to work in the vicinity of the same.

Uncarburetted Water Gas. — The use of uncarburetted water gas for lighting on the incandescent system, has not found adoption to any considerable extent, and need be only alluded to here. The water gas is produced in the usual manner, the producer gas made during the blowing-up process being only applicable to superheating the steam for gas making, or heating the air for the blast. The removal of carbonic acid is of no great importance, but it is necessary to remove the iron carbonyl contained in small quantities in the cold gas. This compound causes a deposit of iron oxide on the mantles or combs used for emitting light, and rapidly reduces their efficiency. It has been proposed to remove the iron carbonyl by passing the gas through strong sulphuric acid, or by heating it to a red heat at a point near the place of combustion, and H. Strache, of Vienna, has patented schemes for purifying water gas by these means in Germany.

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* *Zeitschrift für angew. Chem.*, 1888, p. 465.

CHAPTER V.

OIL GAS.

Oils Used.—The oils most suitable for gas making have been briefly described in Chapter i., and the manufacture of carburetted water gas from oil was treated in the last Chapter. This Chapter will deal only with the methods used for producing pure oil gas with the view mainly to its subsequent use as an enricher of poor gas. Except where other oils are specifically mentioned, it is assumed that the oil used is either Russian Solar distillate or Scotch Gas Oil, both of which are readily obtainable in this country. Almost every conceivable form of retort has at one time or another been suggested for the manufacture of oil gas, and there is no great uniformity in the patterns of the retorts adopted in the processes that have been or are commercial successes. It might consequently be surmised that the shape of the retort exercises only a minor influence on the production of gas, and to a considerable extent this surmise is borne out by the facts. In the processes of a few years standing that have been largely adopted the configuration of the retort appears to have no considerable influence on the gas produced, and consequently the retorts used will here be very briefly alluded to.

Pintsch's System.—The Pintsch system of gas making is very largely used for the production of oil gas for storage under compression for the lighting of railway carriages. The oil is gasified in a double retort—that is to say, it is run on to a tray in one end of a retort, and passes from the other end of that into a retort of similar shape and size placed below the former. The gas formed in the upper retort, in passing through the lower retort, is subjected to a high temperature with a view to rendering it more permanent. Each retort is rather more than 6 feet in length, 10 inches wide, and nearly 10 inches high. The retorts are of cast iron, the upper one being furnished with trays on which the oil drops as it enters the retort; the lower one has no trays. The manufacture is carried on with a considerable pressure (= 4 to 6 inches of water) in the retort, and a bright cherry-red heat is used. The rate at which the oil is supplied varies somewhat according to the quality of oil and the temperature of the retort, but it may be taken at about 2½ gallons of oil per double retort per hour. The richer the gas required, the quicker the rate at which the oil is admitted. Eighty-five cubic feet of gas per gallon of oil is an excellent yield; generally it is rather lower. In the siphons and condenser, which is of simple form, tar is deposited in amount equal to about one-third the volume of oil used. When Scotch oil is used, this tar consists mainly of the higher members of the paraffin and olefine series, with about one-fifth its volume of aromatic hydrocarbons. From the condensers the gas passes through a washer, and thence to a purifier lightly charged with lime or oxide of iron and sawdust. From the purifier it passes to the gasholder, where it is kept under a slight pressure.

The Pintsch gas is generally used for storage under pressure. The gas passes from the holder to the compressing pumps, which force it into cylindrical steel reservoirs to a pressure of about 12 atmospheres. In the pumps and reservoirs a thin, tarry liquid is deposited by the gas, and is known as "hydrocarbon." About 1 gallon of "hydrocarbon" is deposited from 1,000 cubic feet of gas. This hydrocarbon liquid consists mainly of the lower members of the aromatic series. Some particulars of its composition will be found in Chapter xi. The gas is led from the reservoirs by special flexible pressure tubing to the portable reservoirs, affixed to railway carriages, floating buoys, &c. In these the pressure never exceeds 10 atmospheres, and is reduced by special regulators on the outlet pipe to about 0·5 inch of water before consumption. The gas loses in illuminating power by the compression, but even after it has undergone compression, it gives, in suitable burners, an illuminating power equal to 45 to 50 candles, reckoned to a consumption of 5 cubic feet per hour. The burners used consume 0·5 to 0·75 cubic feet per hour. Oil gas made by Pintsch's system is very largely used by several railway companies for carriage lighting, and it answers the purpose excellently. The Great Eastern Railway and some other companies use it almost exclusively throughout their passenger trains. It is also extensively used on buoys and lightships—the floating reservoirs being replenished at intervals of a month or so by a small vessel having storage cylinders. As to the method of manufacture, the oil is cracked at the moderate temperature of the tray on which it falls in the retort, and the vapours are then subjected to the radiant heat from the sides of the upper retort. The oil is thus completely vaporized in the upper retort, and the vapours passing through a neck into the lower retort, are there subjected to a higher temperature of nearly 1,000° C. from heat radiated from the sides of the retort. The temperature is thus raised gradually as the vapours pass through the retort, and surface contact at the high temperature is largely avoided. Carbon is deposited chiefly on the tray on which the oil is vaporized. A considerable quantity of the illuminating gases of the gas is dissolved in the tar and hydrocarbon, and might be recovered and restored to the crude gas.

Pope's System.—Pope's oil gas is also very extensively used for lighting railway carriages, several large companies using little else in their passenger trains. A double retort is used, but there are no trays in either limb. The oil is introduced in a fine spray into the lower retort, and the vapours pass into the upper one for fixing. Contact with heated surfaces is avoided as far as possible, and the oil vapours are subjected to the action of the heat radiated from the sides of the retort. The gas is treated afterwards very similarly to the Pintsch, and is stored, under pressure, in the same manner.

Keith's Apparatus.—Keith's oil-gas apparatus has a retort of about the same size as a single Pintsch, but it is flattened towards the middle of its length, being there shallower but broader. This apparatus, therefore, favours the contact of the oil vapours with the hot surfaces at the constriction, and the result is apparent in the large volume of gas which is produced, though the quality appears to suffer somewhat. This apparatus is used for the supply of lightships, &c.

The oil-gas installations used by some of the railway companies are modifications of one or other of the above systems, in some cases different parts of the installation belong to the competing systems. The retorts are often much modified in design. The systems all agree in subjecting the gas to a temperature of 900° to 1,000° C. before it leaves the retort.

The **Alexander and Paterson retort** (patent specification, No. 3,323, 2nd December, 1885) is rather differently designed. It is a cylindrical, cast-iron retort set horizontally, and having two or more iron pipes passing through the lid to the back of the retort. The oil passes through these pipes, and is heated and partially vaporized therein, the vapours then pass back along the hot retort, where they are permanently gasified, to the outlet pipe near the front of the retort. The pipes are attached to, and are removed with, the lid. The gas on leaving the retort passes through a condenser, and thence direct to the holder, a purifier being considered unnecessary for the Scotch intermediate or burning oils, for which it is specially intended. 14 to 15 gallons of oil are used to produce 1,000 cubic feet of gas, which is of very high illuminating power—*i.e.*, over 70 candles. The retorts are small, each making about 1,000 cubic feet of gas in twelve hours. The process has been used for the supply of gas to country houses and institutions remote from gas works, and is now proposed for the production of gas for the enrichment of coal gas.

Gas made from Oil in the presence of Steam.—Besides the pure oil-gas plants, of which those described may be taken as typical, there are also several in which the oil is cracked in association with steam. The steam either acts as an injector or meets the partially vaporized oil in the retort, in either case being largely decomposed along with the oil. These plants generally have retorts of small diameter, or one retort within another, the annular space being used as a fixing chamber for the gas, and the retorts are often packed with firebrick so as to bring as large a heated area as possible in contact with the gas. The superheated steam prevents to a considerable extent the breaking up of the hydrocarbon vapours with deposition of carbon. Systems depending broadly on the principle of cracking the oil vapours in the presence of superheated steam have been patented by R. B. Avery, A. G. Meeze, H. W. Brooks, and many others, and some few have been extensively tried in the United States. Generally a rather greater volume of gas is obtained than in systems where steam is not used, but the illuminating power is not quite so high. Unless used with caution the steam may prove very disastrous to the life of the iron retorts, and the processes do not appear readily applicable to works where a large quantity of oil gas has to be made.

The Tatham Process.—Rich oil gas is very difficult of consumption in such a manner that its full illuminating value is developed. Thus an ordinary gas burner smokes very much when rich gas is consumed in it; the gas is only partially consumed and the light is obscured. When a burner having a sufficiently small orifice to burn the gas without smoking is used, the temperature of the small flame is sensibly affected by the proximity of the burner, which conducts the heat from it, and the light developed suffers accordingly. Hence very rich gas, say of over 45 candle-power, cannot be burnt to its full power, and its real value must be greater than our burners show. This may be proved by mixing a rich gas in definite proportions with a poor gas, and observing the increase in illuminating power so caused. It will then be found that the enriching value of a rich oil gas is far greater in proportion to its nominal candle-power than that of a poorer oil gas. An ingenious method of developing the full value of a rich gas in burners of moderate size is covered by the Tatham patents. The Tatham process of oil gas manufacture includes the use of certain patterns of retorts which do not differ greatly from those used in other processes, and it may be surmised that the gas made in them is not greatly superior to that made by other methods. Before consumption, however, about 15 per cent. of oxygen is added to the rich oil gas, with the result that it shows on burning an illuminating power of about 100 candles. In fact, it may be taken that the addition of a proper proportion of oxygen to rich oil gas before consumption raises its illuminating power by nearly one-third what it would be if burnt in the most suitable burner without the addition of oxygen. Moreover, a burner of very ordinary proportions may be used for its consumption. The Tatham process, therefore, promises to be a successful rival to the oil gas processes which aim at the production and consumption of a rich gas. The admixture of oxygen does not affect the stability of the gas under compression but rather aids it, and the proportion, lying under 20 per cent. in all cases, of oxygen is far within the limit of security from explosion. It may, therefore, be expected that the Tatham process will be applied to the lighting of railway carriages, &c., as the cost of oxygen can in no case exceed that of its volume of good oil gas, and is likely to become lower year by year. The oil gas installation will of course only be complete with an oxygen-producing plant. The oxygen used has up to the present been made under Brin's process. The condensation products from the gas are returned to the retorts, and the only bye-product finally obtained is a small amount of coke. In this respect the Tatham process is curiously akin to other modern methods of making oil gas.

The Tatham oxy-oil gas has been proposed for use as an enriching material for poor gas, such as ordinary coal gas, and has been tried in a few instances. The valuable effects of the oxygen would not appear to be retained, however, when the oxy-gas is subjected to any considerable degree of dilution. The gas is mixed with the coal gas prior to passing through the purifiers, and, consequently, the oxygen will serve to aid purification, as in the ordinary processes of using oxygen in the purifiers. To retain any advantages the oxygen of the oxy-oil gas may give to the mixed gases on combustion, it is evident that an additional and sufficient amount of oxygen for purification purposes must be added to the gas before it enters the purifiers. The oxygen of the oxy-oil gas should then remain in the mixture at the outlet. But where purification from sulphur compounds is carried out, in order to retain oxygen at the outlet of the vessels, and purify the coal gas from sulphur compounds, the oxy-oil gas would of necessity have to be added to coal gas after the latter had passed the "sulphide" vessels, for if added earlier the oxygen would be retained in them, if only in small amount, and if in large quantity it would decompose the purifying material and render it ineffective. It has been shown that the addition of a small quantity of oxygen, say 1 per cent., to coal gas of about 16 candles, slightly improves the illuminating power, but a quantity much exceeding this deteriorates it. The question of the enriching value of oxy-oil gas appears, therefore, to be narrowed to the issues whether the 1 per cent. of oxygen exercises the same enriching effect on the poor gas as the same volume of oil gas would do, and if not, whether the cost of the oxygen is so much less than oil gas as to compensate for its less value. Probably no one is prepared to maintain that oxygen, volume for volume, is as good an enricher of poor gas as rich oil gas, and the cost of oxygen does not appear to be much less than oil gas of 50 candle-power. If the cost of the production of oxygen is much lowered, its addition to gas may become desirable; but at present the claims of the Tatham process appear to rest on the assumption that the oxygen mixed with the oil gas exercises a greater effect on the illuminating power of the final product than would the same proportion of oxygen added to a mixture in the same proportions of coal gas and oil gas (minus oxygen) immediately before combustion. This assumption may be proved in practice, or the oxygen may be found to exercise in some other way a mysterious effect on the ultimate illuminating value; and several men are prepared to vouch for the greater value of the Tatham oxy-oil gas over other oil gas as an enriching medium, but at the time of writing, the author thinks satisfactory proof of the superiority is still wanting in the published reports on the process.

The Peebles Process.—In recent years a considerable extension of oil gas manufacture has been taking place, owing to the introduction of new processes, of which that devised by Young and Bell, commonly known as the Peebles process, takes first rank. The first important specification dealing with this process is No. 12,421, dated July 5, 1892, and is by W. Young and A. Bell, for "decomposing mineral oils for the production of illuminating gas." Broadly, the process as covered by this patent, and with the subsequent modifications, consists in cracking oil or tar at a low temperature, and washing or scrubbing the gas and vapours produced with oil or tar, which afterwards is itself cracked in similar fashion. The condensing and washing arrangements may be varied considerably, the scrubbing of the gas by the oil being most thorough when it is intended for storage without dilution by coal or water gas. The internal temperature of the retorts, which are cylindrical or nearly so, about 30 inches in diameter and about 8 feet in length, and generally of cast iron, is not much above 550° C. for ordinary mineral gas oil, but is considerably higher for tar and tar oils.

The bottom of the retort is, in recent patterns, protected by an iron plate to prevent leakage of oil through cracking of the retort itself. The gas passes from the retort into a hydraulic main, and thence to a series of condensing tubes and a washer, the patterns and disposition of which may vary, but which serve to subject the gas to contact with the oil that is passing from the reservoir to the retort. The oil washes and condenses from the gas all hydrocarbon vapours that are not of the nature of an ordinarily permanent gas, and these are, therefore, returned to the retort with the fresh oil. It will thus be seen that the process is practically one of distillation at a temperature that effects only partial cracking up of the hydrocarbons, and fractionation of the products of the distillation, all but the most volatile being eventually returned to the cracking chamber. The carbon set free on the breaking up of the hydrocarbons is deposited in the retort, and is removed at intervals compacted into a good homogeneous coke free from ash. The process thus produces only permanent gas and coke of good quality, and, moreover, does this in such a manner that the cracking is not severe, and, consequently, the yield of coke is low compared with the gas produced and the oil carbonized. The amount of coke from Scotch gas oil is 5 to 6 cwts. per ton of oil. The volume of gas from such oil is about 22,000 cubic feet per ton, and its illuminating power is generally stated at about 90 candles, a value calculated from its enriching power on poor gas. These figures would give a yield of from 1,500 to 1,600 candles per gallon of oil; but it will be found that if the illuminating power of oil gas made by other processes is taken at its enriching power, the result is very similar. The figures are perhaps in favour of Peebles gas, which has also the advantage of greater permanency. The process undoubtedly submits the oil and gas to a systematic treatment, and should preserve as far as possible the illuminating value of the oil. The retorts are by the early specification heated externally, in similar fashion to coal gas retorts, and for small installations this is the most convenient method. In a later development of the process the inventors utilize the economy of internal heating, and produce a certain amount of water gas in the same plant. This modification is covered by Wm. Young's patent, No. 12,355, dated June 23rd, 1893, entitled, "Improvements in the production of illuminating gas from mineral oils, and in apparatus therefor, and for producing water gas." The washing and condensing arrangements are very similar to those of the earlier pure oil-gas process; but the oil is sprayed into the upper part of a tall producer, in the lower part of which is a bed of fuel. Producer gas and water gas are produced by blowing air and steam at intervals through the latter, and while the blast is shut off, or when only a small amount of water gas is being made, the oil gas is made in the upper part of the producer, the oil being cracked by the heat radiated from the sides of the chamber, or if this is insufficient, by the upper layer of the fuel. The carbon thrown down by the decomposition of the oil is deposited on the fuel. When the heat of the fuel has fallen considerably, air is blown in, and the carbon monoxide burnt by a secondary air supply in the upper part of the chamber. The process is largely regenerative, and several modifications of the plant have been devised to meet various needs. The Young process, as thus developed, is really a carburetted water-gas process, but is described here since it was the outcome of the simple Peebles oil-gas process. The new process obviates the difficulties of cracked retorts which were frequent with the older one, and where a large make is needed, is certainly more economical. The Peebles process, in one or other of its forms, has been adopted pretty extensively, especially in Scotland, and as far as published results at present show, it has given satisfaction.

CHAPTER VI.

ENRICHING BY LIGHT OILS.

Carburetting Gas and Air.—The method of enriching, or raising the illuminating power of gas of which this chapter treats is commonly known as carburetting, or more explicitly, as cold carburetting. It consists in adding to gas a proportion of the vapour of very volatile liquid hydrocarbons, such as are described under the fourth class of raw materials on p. 39. Occasionally air is saturated with such light hydrocarbon vapours to form an illuminating gaseous mixture, but owing to the large volume of nitrogen necessarily present in such a gas, it is evident that the resources of the hydrocarbon are wofully misspent in such a method of consuming it for the development of light. This so-called air gas can only be safely consumed in special valved burners, and with precautions to avoid the explosion of the gas in the services and holder. The uneconomical nature of this gas, and the danger attending its use without special precautions, are sufficient grounds for preventing its common adoption in this country.

Carburetting with Carburine.—The great advantage of carburetting gas with light oil vapours is the ease and rapidity of the process, and the small bulk and simplicity of the apparatus employed. Where a statutory illuminating power has to be maintained, the method may be the sole means of enriching used, or may serve as supplementary to the carbonization of cannel and heavy oils. In the largest works it has hitherto been used only to supplement other processes of enriching, and for this purpose it is admirably adapted. In this country the carburetting material used is almost invariably carburine, or light petroleum oil, and it is used with apparatus constructed under the Maxim patents, which are administered by the Gas Lighting Improvement Company, Limited. The apparatus is in use at several London works and distributing stations. Fig. 26 is a sketch of it, with the necessary accessories and connections. P is the gas main, which may be either the inlet main to the gasholders or the distributing main. The store-tank for the carburine, A, is provided with inlet and outlet pipes, B and C, respectively for the fluid, and a float, D, to indicate the amount contained. The pump draws the carburine from the store-tank through the tube, F, into the evaporator, E. The evaporator resembles a vertical tubular boiler, and is fitted with water gauge, G, and pressure gauge, H. Steam plays round the tubes and escapes through J, evaporating the spirit in the tubes, the vapour being forced by its own pressure through the tube, M, to the regulating valve, N, and injector, O, which is connected to the gas main, P, by the pipes, Q and R, a short distance apart. The storage tank is generally of steel, and sunk

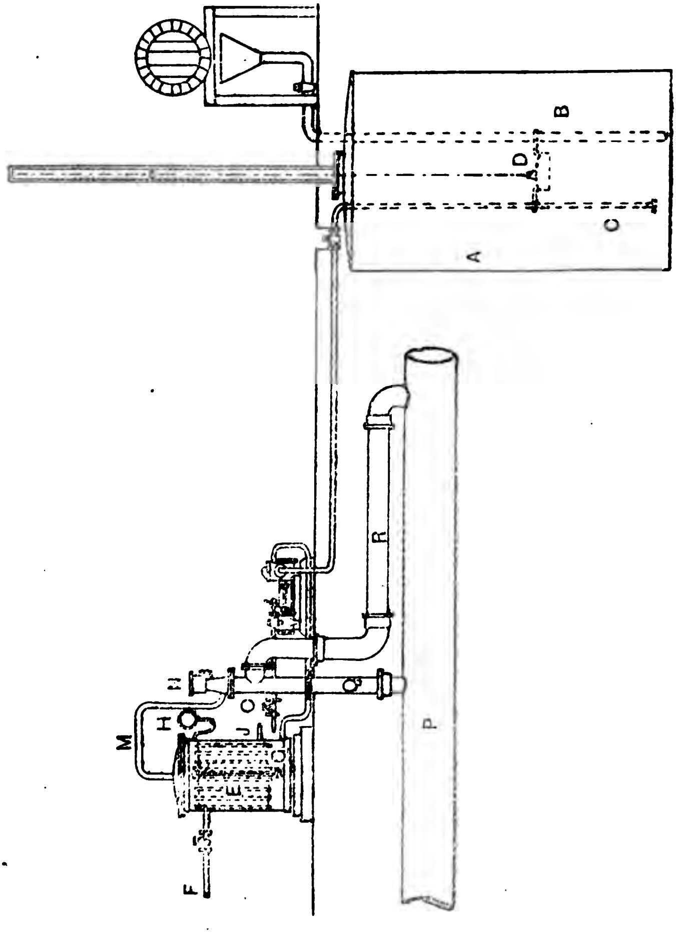

Fig. 26.—The Maxim carburetting apparatus.

P, Gas main; A, store tank; B, C, inlet and outlet pipes to carburine store tank; D, float; F, pipe leading to evaporator; E, evaporator; G, water gauge; H, pressure gauge; J, steam escape orifice; M, outlet pipe for vapour; N, regulating valve; O, injector; Q, R, pipes leading to gas main.

in the ground; it has a small diameter ventilating tube passing through the crown, and carried up to a safe height. The amount of carburine vapour admitted to the gas at any time is controlled by the regulating valve, N, and may be adjusted to a nicety. With gas of about 15 to 17 candles, it appears from observations made by men of repute, that 1 gallon of carburine, having a specific gravity of about 0·680 suffices, when vaporized in this apparatus, to raise about 8,000 cubic feet of gas 1 candle in illuminating power. The gas so enriched is as permanent as gas of the same quality produced by most other methods. The quantity of hydrocarbon vapour that gas can carry at any particular temperature obviously depends, primarily, on the vapour tension of the hydrocarbon at that temperature. Carburine being a mixture, it is difficult to exactly calculate from vapour tension determinations the amount of its vapour required to saturate gas at any temperature. Practically no considerable error is, however, introduced by regarding carburine as hexane, and then from the vapour tension of hexane it may be calculated that gas saturated with carburine vapour contains at 0° C. 8·0 per cent. by volume, and at 15° C. (59° F.) 15·6 per cent. by volume of that vapour. A gallon of carburine gives 28·3 cubic feet of vapour at 0° C., or 29·85 cubic feet at 15° C., and, therefore, saturates about 355 cubic feet of gas at 0° C., or 190 cubic feet at 59° F. Even supposing that the gas, after enrichment with carburine, will be subjected to a temperature of 0° C., it is evident that there is ample margin for it to retain in suspension carburine vapour equivalent to an enrichment of several candles in lighting value. It may be mentioned that Professor Wm. Foster has given 162 cubic feet as the amount of 16-candle London gas, which can retain the vapour of 1 gallon of carburine at 59° F. and the normal barometric pressure. This value was found experimentally.

The advantages of so simple and expeditious a method of enriching gas, as carburetting with light petroleum vapour, are too obvious to need more than mere enumeration. They are the saving of coke, and the production of no inferior coke from cannel coal; absence of purification, and of storage gasholders for the enriching medium; compactness of enriching plant, and saving of labour. The economy of the process depends on the current market rates for carburine, and the cost of enrichment by it may readily be calculated for any particular case from the price of carburine and the data given above.

Carburetting with Benzol Vapour.—Passing to enrichment by benzol vapour, which has lately had many advocates in Germany, it may be stated, preliminarily, that the process is not used at present on a large scale in this country, and that the results of early attempts in that direction, and the balance of opinion of competent English gas engineers are against it. The results of experiments in Germany are, however, so favourable to it, that carburetting by benzol must certainly be considered an alternative to other good methods of enrichment. Dr. H. Bunte, who has strenuously advocated benzol for enriching purposes, discusses the problem on the same lines as have been followed above for carburine.* The vapour tension of benzene, the chief constituent of commercial 90 per cent. benzol, is at 0° C. (32° F.) 25·3 mm., and at 15° C. (59° F.) 58·9 mm. From these numbers it may be deduced that benzol vapour will form 3·3 volumes at 0° C., or 7·75 volumes at 15° C. per cent. of a gas saturated with it. These numbers are lower than the corresponding ones for hexane, and hence it might be considered that benzol would be a less efficient carburetting agent than carburine. According to Dr. H. Bunte, however, benzene vapour has, volume for volume or weight for weight, a far higher enriching power than hexane or other paraffins. Weight for weight, he finds benzene secures nearly two and a-half times the lighting effect of hexane, and he argues that the aromatic hydrocarbons have a far greater lighting effect than the members of the paraffin and olefine series which have the same number of carbon atoms to the molecule. He estimates† that 1 gallon of benzol will raise at least 24,500 cubic feet of coal gas of about 16 candles by 1 candle in illuminating power. Therefore, volume for volume, benzol does three times the work of carburine as an enriching agent, or, weight for weight, about two and one-third times the work. The use of benzol for carburetting has been attended with excellent results at the Munich gas works,‡ according to the testimony of H. Ries and E. Schilling. The apparatus used consists of a vessel containing a drum, which is moistened continuously by the benzol, through which the gas passes. The large surface wetted with benzol, presented to the passing gas, ensures the thorough saturation of the latter with benzol vapour. The amount of gas passing through the carburettor is proportioned to the degree of enrichment required, but, in all ordinary cases, is small in proportion to the total volume of gas to be enriched. A branch service from the main leads to the carburettor, and another service conveys the gas from the latter again into the main stream. By careful adjustment of valves, the amounts of gas going direct along the main and through the carburettor are regulated to give the precise required degree of enrichment to the gas. The comparatively low vapour tension of benzene and toluene, at ordinary temperatures, would seem to put the permanency of enrichment by them much in question, but there appears to be ample margin even at 0° C. (32° F.) for the retention by gas of sufficient benzol vapour, to give it an illuminating power of 25 candles. The cost of carburetting by benzol can be calculated from the current market prices, approximately, by the aid of the above data. The material should conform in its range of distillation to the limits for 90 per cent. benzol; 50 per cent. benzol is far less reliable; but the source of the material is of little importance, as the presence of volatile hydrocarbon impurities is of no moment for carburetting, though deleterious to benzol intended for use in chemical works. It is but fair to add that the high value of benzene as an enriching agent, compared with other hydrocarbons, has been doubted by Lewis T. Wright[*] and others, but no experimental data in support of the aspersion have come to the author's notice up to the present time.

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* *Journ. f. Gasbeleuchtung*, vol. xxxvi., p. 442; and *Journ. of Gas Lighting*, vol. lxii., p. 717.

† *Journ. f. Gasbeleuchtung*, vol. xxxvii., p. 81; and *Journ. of Gas Lighting*, vol. lxiii., p. 485.

‡ *Journ. f. Gasbeleuchtung*, vol. xxxvii., pp. 1, 549; or, *Journ. of Gas Lighting*, vol. lxiii., p. 197, and vol. lxiv., p. 735.

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[*] *Journ. Soc. Chem. Ind.*, vol. xiv., p. 107.

CHAPTER VII.

FINAL DETAILS OF THE MANUFACTURE AND SUNDRY SCHEMES FOR MAKING AND ENRICHING GAS.

THE ordinary processes of gas manufacture and enrichment have now been described, and the course of the gas traced up to the last stage in its purification. The measurement, storage, and distribution of gas scarcely fall within the scope of this work, but the more important apparatus for these purposes will be considered very briefly in the latter half of this chapter, and the treatment of the gas, up to the time that it leaves the works, thus dealt with for the sake of completeness, though the final stages lie almost wholly within the engineers' province. There are, however, a few subsidiary processes for gas enrichment, &c., which do not fall appropriately within any of the classes adopted in the earlier chapters, but which are of sufficient interest to demand some notice, and to these the next few pages will be devoted.

Dinsmore's Process for Carbonizing Tar.—Many schemes for the carbonization of tar and tar oils are merely simple adaptations of the ordinary oil gas and carburetted water-gas processes. But the methods of carbonizing tar, patented by J. H. R. Dinsmore, fall in a somewhat different category. He endeavours to gasify as much as possible of the tarry vapours in the crude gas, and the tar deposited near the retorts, in the presence of the coal gas itself. By one of his patents he condenses the tarry matter from the gas by passing it, as it leaves the retort, through inclined ducts, the ends of which are artificially cooled. The tar so condensed runs down to the hot part of the retort, and is there vaporized. The Dinsmore process has been tried at several works, but has succeeded best at Widnes, where it has been in use for some years. The engineer in charge of this works, Isaac Carr, has obtained better results than others, even with what would commonly be considered bad coal for gas making. The gas passes from the ordinary retorts through a heated retort or duct, where tarry matters are to a very large extent gasified, and the quality and quantity of gas obtained from the coal greatly enhanced. On the working scale other operators have not been so successful as Isaac Carr, and perhaps his success may be largely due to a careful regulation of heats, and the passage of gas of tolerably uniform composition through the secondary retort. To judge by the present attitude of gas managers to the Dinsmore process, it would seem that it is not likely to be adopted extensively, and, indeed, were it not for the notable exception at Widnes, it might be relegated to the list of well-conceived schemes that have failed to justify themselves on trial on the practical scale. It may be observed in this connection that Lewis T. Wright in a paper entitled, "What shall we do with our tar?" read before the Society of Chemical Industry,* gives results which go to prove that no rich gas can be obtained from coal tar or tar oils, and that tar is practically useless as an enricher. On the other hand, his results for benzol are at variance with those more recently obtained in Germany, and as the method of destructive distillation applied by him to tar differed in many essential points from that of the Dinsmore process, he cannot be considered to have proved the results claimed for the latter at all improbable. Most methods of carbonizing tar are fruitful of blocked ascension pipes and mains; but the Dinsmore process is an exception.

Acetylene as an Enriching Agent.—A novel scheme for enriching poor gas, or making a high-value illuminating gas, has recently emanated from the United States, and is of peculiar interest to the gas chemist, as pointing to the growing importance of chemistry to the gas industry. The American experiments were subsequent to the researches of Moissan on the combination of carbon with certain of the metals of the alkaline earths, and especially with calcium. Calcium carbide, CaC_2, decomposes with water, and yields acetylene and lime, in accordance with the equation—

$$CaC_2 + H_2O = C_2H_2 + CaO.$$

The yield of acetylene is 0·4 of the weight of calcium carbide decomposed. T. L. Wilson, of an aluminium company in North Carolina, found that calcium carbide could be readily produced on a large scale by fusing carbonaceous matter and chalk or lime in a properly constructed electric furnace. To this discovery the commercial production of acetylene is due. Its cost must depend largely on the cost of electrical energy, and as water power was available at Wilson's works, the estimates originally given were formed when working under very favourable conditions. These estimates put the cost of producing calcium carbide at £4 a ton, and the lime formed as a bye-product would have a considerable market value. A ton of calcium carbide is capable of yielding nearly 13,000 cubic feet of acetylene. The net cost of the gas should, therefore, be only about 6s. per 1,000 cubic feet, but to this must, in nearly all cases, be added a considerable sum for the cost of electrical energy, and several small items. It has been calculated from the known customary cost of electrical energy obtained through the medium of a steam engine, that 1,000 cubic feet of acetylene would cost about £10, which is altogether too high an estimate. It must be admitted, however, that where water power is not available, the cost of calcium carbide, and, consequently, acetylene would seem to be very high, if not absolutely prohibitive to its employment for ordinary purposes of illuminating. Acetylene burns with a white, clear flame, in small flat-flame burners, and thus burnt, has a higher illuminating value than any other gas. Its illuminating power, calculated to a nominal consumption of 5 cubic feet per hour, is about 240 candles. It would appear, however, that the illuminating power is not in the same ratio when the acetylene is mixed with poor gas, and consumed in a large burner, but is, indeed, very much less. It would, therefore, seem extremely improbable that, under present conditions, acetylene will ever come into common use as a carburetting agent. Distributed in steel cylinders under compression, it should compete with rich oil gas for the lighting of buoys, railway carriages, &c. The gas might be produced in the cylinder itself, by inserting the requisite amount of calcium carbide and water—the two being kept apart by some means until the cylinder is securely closed. It would seem, however, that acetylene from calcium carbide would be dearer than oil gas when steam-power has to be used for the production of the carbide, but either the carbide or the liquefied gas would have immense advantages over oil gas in respect of portability.

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* *Journ. Soc. Chem. Ind.*, 1886, p. 558.

Station Gas Meters.—Reverting to the treatment of coal and other gas after it has passed through the purifiers, it will almost invariably be led thence to a station meter for the exact measurement of its volume. The meter is a necessary adjunct to a gas works, to record the amount of gas made per day and hour, and if the works is a large one, a meter will be assigned to the output of each retort house, or connected to the outlet of each set of purifiers, according to the arrangement of the works. The use of separate meters to each house or each section in a large works, affords a useful indication of the relative carbonizing efficiency of the houses. The works or station meter is invariably of the variety known as "wet," from the use of water as a confining medium within it. The meter is usually placed between the outlets of the last purifying vessels in each set and the inlets to the gasholders. It consists of an outer case, rectangular in the larger, cylindrical in the smaller, meters. Within this case is a cylindrical drum having a horizontal axle, by which it revolves within the case. The drum consists of three or four equal chambers—the partitions being set angularwise to the axis, so as to offer little obstruction to the revolution of the drum under water. To one end of the cylindrical drum is affixed a cover forming a convex end to the cylinder. The inlet pipe passes through this cover in the line of the axle, and is turned upwards within the cavity between the cover and the chamber walls. The meter is throughout filled with water to a level slightly above the axle, and the inlet pipe must turn upwards until well clear of the water. The gas passes into the cavity between the cover and chambers of the drum, and by a suitably-placed inlet slit into one of the chambers. The gas entering the chamber as it is partially immersed in the water, by its lightness, tends to raise that chamber and draw it out of the water. The drum axle being set in bearings, and the drum, consequently, not free to rise bodily, the effect of the gas entering the chamber is to cause the drum to revolve. As soon as the chamber is filled with gas, the inlet to it has, by the revolution of the drum, passed beneath the water level, and sealed the gas up; the inlet to the next chamber rising at the same time above the water level, and permitting the gas to enter that chamber. As the inlet to each chamber becomes sealed, an outlet slit opening into the cavity between the drum and the outer case is unsealed, and water entering by the inlet forces the gas through this slit to the afore-mentioned cavity, from which it is conveyed by the meter outlet pipe, which merely passes through the outer case some distance above the water level. The same process occurs with each chamber, the pressure of the entering gas driving it through whichever chamber inlet slit may be unsealed, and thereby, owing to the gas drawing that chamber from the water, causing revolution of the drum. When a chamber is filled with gas, the revolution of the drum automatically seals the inlet slit and unseals the outlet slit. The axle of the meter is carried outside the case, and has fixed on its extremity a toothed wheel, which gears into a clockwork mechanism for recording from the number of revolutions of the drum and axle, the volume of gas passed through the meter. It is evident that the capacity of the chambers of the drum is affected by the level of the water in the meter, and a rise or fall in the water will diminish or increase the volume of gas passed at each revolution of the drum, and cause an incorrect registration of the volume of gas passing through the meter. The meter is, therefore, furnished with a small continuous supply of water, and a siphon overflow pipe is provided to draw off the water as soon as it rises above the normal water-line. The recording mechanism is affixed to a series of small dials, arranged so that each registers quantities ten times those registered on the preceding dial. The volume of gas passed may, therefore, be found at any time by setting down in order, from right to left, the figure on each dial which its pointer is passing, or has last passed, beginning with the dial for the unit quantity (generally 100 or 1,000 cubic feet) recorded by the meter, and multiplying the number so obtained by the said unit. By subtracting the reading at one time from that at a later period, the quantity of gas passed in the interval is found. Various mechanical contrivances have been devised for compensating for alteration of water level in small meters not provided with a continuous water supply and overflow.

Station Governor.—The governor is an apparatus designed to deliver gas at a uniform pressure from a source where the pressure is subject to variations, the latter being in many instances sudden and considerable. It further enables the pressure to be regulated and fixed at any desired amount by some simple adjustment. A governor is generally attached to an exhauster to maintain a uniform pressure, and prevent either the vacuum or pressure becoming too great. A portion of the gas is led by a small pipe off the main into the bell of a small gasholder. The rise and fall of the bell under the varying gas pressure are made to act on a throttle valve in the steam-supply pipe to the exhauster, so as to alter the speed of the latter according to the pressure of the gas. In some instances, the rise and fall of the bell of the small holder of the governor is used to control a valve on a bye-pass between the inlet and outlet pipes of the exhauster; the opening of the valve allows a certain quantity of gas to pass back from the outlet to the inlet main. This form of governor is especially used to control the exhausters used for maintaining a definite pressure in the hydraulic main and retorts. When the pressure on the inlet side of the exhauster becomes too low, the governor-bell connected to the bye-pass valve opens the latter, and allows some of the gas to return. Exhausters are generally used for providing the requisite pressure for the distribution of the gas, and as this pressure must be readily regulated and uniform, governors are used to control it, as well as in smaller works, where the pressure of the holder is sufficient for the purposes of distribution. As the pressure thrown by the holder, especially if it be telescopic, varies considerably, and as, generally, two or more holders throwing different pressures are used in turn, it becomes essential to have a means of easily controlling the pressure at which the gas leaves the works. For these purposes various forms of station governor have been designed, most of them being primarily dependent on the same general principle.

The early station governor consisted of a small gasholder, the weight of the bell of which was balanced to the required degree by weights attached to the free end of a chain passing over pulleys, and having the opposite end attached to the centre of the bell crown. The gas inlet pipe passes up the centre line of the holder, terminating a little above the water line, but having the end partially closed by a flange. The outlet pipe is either formed by the annular space between the inlet pipe and a larger co-axial pipe, or is at one side of the inlet pipe. Suspended by a chain from the centre of the bell crown is a conical weight within the inlet pipe, the apex of the cone pointing upwards, and the base being of considerably smaller diameter than the inlet pipe, but larger than the orifice of the latter. A rise in the gas pressure forces the bell upwards, and so draws the cone up to the inlet pipe flanged outlet, partially closing the latter, and diminishing the volume of gas admitted to the bell until the pressure within the latter again falls. The conical weight or valve plug has in practice generally given place to one of which the sides are made to a parabolic curve, such that, for equal rises in the valve plug, the opening from the inlet tube becomes restricted to an equal extent. This renders the weighting of the holder bell to deliver gas at any desired increase or decrease of pressure a simple matter, and also permits a rough estimation of the amount of gas passing from the height of the plug, on which the size of the opening is dependent in a regular proportion. This simple governor is shown in Fig. 27. The pressure of the

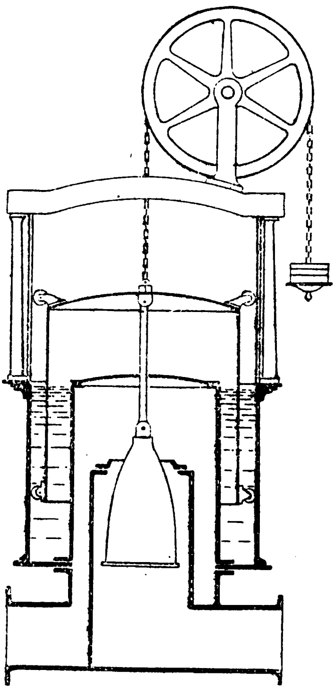
Fig. 27.—Simple governor.

outgoing gas is in practice controlled by adding to or taking from the balance weight, weights each equivalent to a definite alteration in pressure. The area of the base of the plug must be considerably less than that of the bell, or the changes in pressure of the entering gas will affect the outgoing gas. To prevent the disturbing effect produced by changes of pressure, even with governors having tolerably large bells, various compensating arrangements have been devised, and one or other of them is now generally incorporated in this form of governor. With the early governors the bell might by accident become tilted, and permit an escape of gas; the more modern forms are not open to this objection. For some purposes it is desirable to have a governor fitted with an apparatus for automatically changing the pressure at certain fixed times, and such an automatic pressure changer has been put upon the market.

The Gasholder.—The gasholder is at present constructed on essentially the same principle as in the early days of gas lighting. It consists of a bell-shaped vessel having its lower open end immersed beneath water in a tank, and maintained in equilibrium by a suitable fixed framework. The interior of the bell serves as the gas reservoir, the confining media being the sides and top of the bell and the surface of the water in the tank. The inlet and outlet pipes for the gas pass up through the bottom of the tank to a short distance above the surface of the water; as gas passes into or out of the bell, the latter rises or falls accordingly, its stability being ensured by the external framing on which it travels by means of grooved wheels.

The **gasholder tank** may be constructed of various materials, according to the size of the holder and the nature of the soil. For small holders and those on a very porous soil, iron tanks are sometimes used, and these may be either partially or wholly above ground. In general, however, sound tanks perfectly water-tight may be constructed of concrete, brick, or stone, either backed with puddle or not, according to circumstances. Where the soil is good plastic clay, little or no puddle is required, and the tank walls need be but thin, as the soil will give support and the requisite impermeability. In this case also little more than an annular excavation need be made, the greater part of the original soil being left as a mound in the tank, covered with a thin layer of good Portland cement, concrete, or masonry. Where the soil is less firm, the excavation may have to be carried on until a nearly level bottom to the tank is obtained. Some engineers invariably use puddle as a backing to the walls and bottom of a tank, and thereby secure the impermeability of a clay soil. Others rely on good concrete, or brick or stonework rendered with Portland cement. The inlet and outlet pipes of the holder are carried under the retaining wall of the tank, and up within it to a short height above the water level. The tank walls generally rise somewhat above the natural level of the land, the earth removed in the excavation serving to raise the level in the immediate neighbourhood of the tank. The tank walls are provided with guide rails at regular intervals throughout the circumference, on which the guide rollers on the lower curb of the gasholder bell travel as the latter rises or falls in the tank. In the tank walls are constructed substantial piers of stonework or concrete, for the support of the standards of the guide framing. In each pier, 6 or 8 feet below the surface, are the anchor plates, firmly secured in the masonry. To these are attached tie-bolts of the required length to secure the base of the guide column to the pier.

The **framing of the holder** consists of a number of vertical columns placed equidistant from one another in a circle concentric with the tank wall, but of slightly greater radius. Cast iron was formerly used for these columns, but in most recent structures wrought-iron lattice standards have been used. These generally taper uniformly from bottom to top, and each standard is united by lattice girders to the adjacent standards at the top, and at one or more points below, the number of these horizontal girders increasing with the height of the framing. The framing thus forms a number of approximately rectangular spaces, which are generally each traversed by diagonal tension rods. In some cases other plans of tying the frame are adopted. The framing forms a cylindrical piece of trellis-work, within which the bell of the holder is placed. The bell consists of iron plates built on to a light framing, forming a hollow cylinder, the diameter of which is rather less than that of the tank, with one end closed by a domed roof of plates. The open end of the cylinder dips into the water in the tank. The framing of the bell, if of considerable size, may be trussed both at the top and sides, and both the bottom and top curbs must be well strengthened, the plates adjoining them being of greater thickness than elsewhere. Opinions differ considerably as to the relative merits of trussed and untrussed roofs of holders. Opposite the standards of the framing are affixed to the sides of the bell, near the upper curb, carriages for the guide rollers, which traverse rails on the inner face of each standard of the framing. The arms of the carriages bearing the rollers are of such length that there is very little play between the rollers and the rails on the standards. The lower curb of the bell is also furnished with rollers, which traverse rails fixed on the tank wall. Where a trussed roof with central king-post is used, a pier is carried up in the centre of the tank for the bottom of the king-post to rest on when the bell is in its lowest position, and the roof is unsupported by the gas within. In other holders a substantial wooden framing is erected in the tank for the support of the top or crown of the bell when the latter is in its lowest position.

Mode of Using the Holder.—When the holder is in use, the tank is filled with water nearly to the top, and the gas within is under the pressure due to the weight of the bell. The pressure of the gas, of course, depresses the water within the holder, and the sides of the bell must always be immersed in the water of the tank to a depth greater than the depression so caused, or the gas will escape from under the sides of the bell. The pressure on the gas within a holder varies from 1 inch to 12 inches of water, according to the weight and dimensions of the holder bell. To pass gas into the holder, it must be pumped at a greater pressure than that thrown by the holder. The holder pressure may, with or without the intervention of a governor, serve for the distribution of the gas, though in large works the gas is generally withdrawn from the holders by the aid of an exhauster.

Telescopic Holders.—It is evident that the capacity of the holder, as here described, is limited for a given diameter by the depth of the tank. In some localities the difficulties of making a deep tank are very great, owing to the nature of the soil, and, in any case, the limit to which its depth can be profitably carried may be put at about 60 feet. In positions where ground is very valuable, the multiplication of holders becomes very expensive from the space alone which they occupy. Consequently holders, if of at all considerable dimensions, are now constructed on the telescopic principle, whereby the capacity may be practically doubled, trebled, quadrupled, or even still further increased for a given tank. The bell of the holder is formed of two or more concentric hollow cylinders, one sliding within the next larger. The smallest or inmost cylinder is alone roofed, the upper edge of the sides of the other cylinders being turned over inwards, and carried down parallel to the cylinder side to a depth of about 3 feet. The lower edge of the next smaller cylinder is turned outwards and upwards to the same height, forming an annular trough, which is filled with water. Into this water the turned-over edge of the larger cylinder dips, and a gas-tight seal is thereby formed. The upper curb of each lift, so constructed, of the bell is furnished with arms as carriages for rollers traversing the guide-framing rails. The carriages of the inner lifts are necessarily longer, and must be proportionately stronger than those of the outer lifts. The cup or seal of each lift need be only 1 to 2 feet in diameter; consequently, the capacity of the inner lift is not very much less than that of the outer. Rollers are attached to the outside of the lower curb of each lift, and traverse rails attached to the inside of the next larger lift, in the same manner as the lower guide rollers of a single holder, or of the outer lift of a telescopic gasholder, run on rails on the side of the tank. When down, the lifts of the holder rest on bed plates at the bottom of the tank, the crown of the inmost lift being supported as in single holders. Lack of space prevents the details of the construction of large telescopic gasholders being here given, but the general principles on which they act may be gathered from the illustration—part in section, part in elevation—of a four-lift holder (Fig. 28). For the sake of clearness, minor details are omitted. In the illustration guide-framing is shown for the whole of the lifts, but some holders have been constructed in which external guide-framing has been

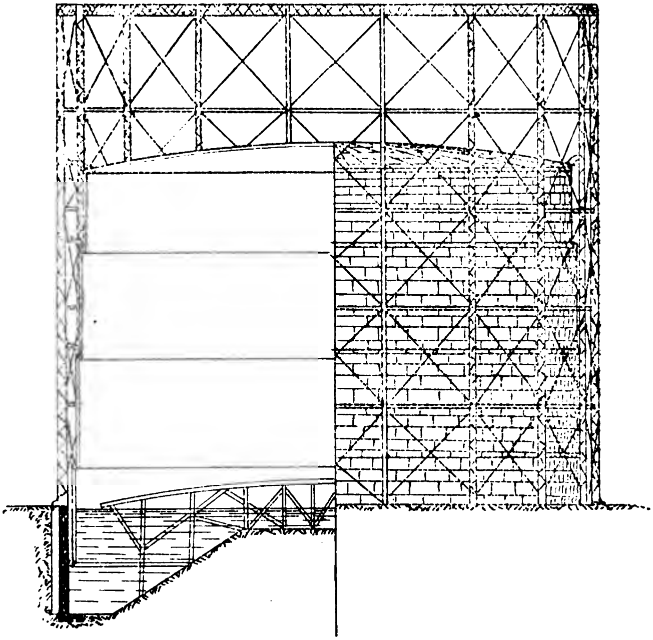
Fig. 28.—Four-lift gasholder.

dispensed with for the inner lifts. As soon as cupping takes place, the weight of the next lower lift is thrown on to the cup of the upper one, and effectually keeps the latter in a position of stability. Rope guides have also been considerably used in recent years. For particulars of these later developments in gasholder construction, about which controversy still rages, the current technical journals should be consulted. Gasholders have now been made of 300 feet diameter, and with as many as six lifts, and several exist having capacities from 7,000,000 to 12,000,000 cubic feet.

With telescopic gasholders, interference with, and even danger in, working occurs, from the freezing of the water in the lutes. Though not so much felt in this country as elsewhere, the annoyance and risk are sufficiently grave to make the adoption of some preventive means general. The most convenient is the passage of steam into the lutes by means of flexible tubing, which is supported on a series of pulleys attached to the guide-framing. This method has been patented by S. Cutler & Sons. One eminent engineer has proposed to warm the water in the lute by means of a series of Bunsen burners.

From the gasholders the gas is generally pumped into the distributing mains, and with its departure from the works the chemist may be said to have done with it, except in so far as he may have to examine it at some point in the distributing system, to see that the amounts of certain impurities in it are not excessive. For the details of such examination, the following chapter must be consulted.

CHAPTER VIII.

GAS ANALYSIS.

It is occasionally required at a gas works to know the proportions in which all the constituents of a sample of gas are present in it, and still more often is it requisite to ascertain rapidly, and with tolerable exactitude, the amounts of one or two constituents. For the complete and exact analysis of a complex mixture, such as coal or oil gas, considerable experience in working the particular form of apparatus used is required, and the special text-books and papers on the subject of gas analysis must be consulted. Here, only the general principles involved in the analysis and a few hints on working can be given, and the remainder of the chapter will be devoted to the estimation of certain constituents which have a special import to the gas manufacturer. The reagents commonly used in gas analysis, and the precautions to be observed in using them, are mentioned below.

Reagents Required.—**Potassium hydroxide** is used as a strong solution. For exact work, half a pound of commercial stick potash should be dissolved in a pint of distilled water. For rough determinations, a more dilute and, consequently, less syrupy solution may be used. On no account must the stick potash sold as "purified by alcohol" be used for making up a solution for the analysis of illuminating gas, as it will cause error in the determination of the hydrocarbons. This reagent is used chiefly for the determination of carbon dioxide, but it also absorbs hydrogen sulphide, cyanogen, hydrogen cyanide, and hydrocarbon vapours; hence, care is needed in applying it to secure exact results.

Pyrogallic acid should be freshly dissolved as required for use in about three times its weight of distilled water. It is passed into the absorbing vessel, and followed by about eight times its volume of strong caustic potash (not alcoholic) solution. The solution of potassium pyrogallate so obtained is an active absorbent of oxygen. The gas from which the oxygen is to be removed must be agitated with the reagent for five minutes, as the absorption takes place somewhat slowly. A trace of carbon monoxide is formed by the action, but it amounts only to about 0·2 per cent. of the oxygen absorbed, and in most cases the error therefrom will be less than that of the reading of the volumes. From its affinity for oxygen, it is difficult to keep a solution of potassium pyrogallate in good condition, and it is, consequently, better to form it as required in the absorption vessel itself.

Phosphorus in the form of sticks has been proposed by Lindemann for the estimation of oxygen in a gaseous mixture by absorption. Its action is interfered with by ethylene and other hydrocarbons, so that it is not desirable to use it in the analysis of illuminating gas.

Cuprous chloride is used in gas analysis either in ammoniacal or hydrochloric acid solution. The ammoniacal solution has a greater absorbing power for carbon monoxide, and is slightly preferable for other reasons, but is not so conveniently prepared as the acid solution, which answers admirably for most technical analyses. To prepare the ammoniacal solution, 40 grams of the precipitated cuprous chloride is put into a 500 c.c. measuring flask containing about 400 c.c. of water. Ammonia is then driven off by boiling some strong solution in a flask, the outlet tube of which leads into the flask containing the cuprous chloride. When the cuprous chloride solution has assumed a pale blue colour, the stream of ammonia is stopped, and the copper solution made up to 500 c.c. with water. Care should be taken to avoid access of air to the cuprous chloride solution, which must not be more dilute than the above quantities will produce. The hydrochloric acid solution of cuprous chloride is prepared by pouring 500 c.c. of concentrated hydrochloric acid on 100 grams of precipitated cuprous chloride in a bottle fitted with a well greased stopper, or a caoutchouc bung. Two or three spirals of copper, readily obtained from the turning shop, should be placed in the solution, and should reach to the top of the bottle. When free from oxidation products, the cuprous chloride solution in hydrochloric acid is clear and colourless. The ammoniacal solution of cuprous chloride absorbs carbon monoxide, ethylene, and acetylene completely, and other hydrocarbons and oxygen partially. Hence, it is necessary to remove oxygen and hydrocarbons from a gas before applying cuprous chloride solution to estimate the carbon monoxide. W. Hempel first observed the absorption of ethylene[*] by cuprous chloride, and pointed out that even in producer or water gas, any hydrocarbons present should be absorbed before the cuprous chloride solution is used, or the latter will become contaminated, and give off hydrocarbons when being used later for the absorption of carbon monoxide in another sample, and the error from this cause may be so great that the use of cuprous chloride, which has thus been allowed to become saturated with hydrocarbons, may cause an increase in the volume of a gas under analysis, even when some carbon monoxide has actually been absorbed. Cuprous chloride solution that has been much used for absorbing carbon monoxide does not take up the last traces of that gas from a gaseous mixture; therefore, in accurate analyses, the gas should finally be agitated with cuprous chloride solution that has not been used previously.

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[*] *Berichte d. d. Chem. Gesellschaft*, vol. xx., p. 2344.

Fuming sulphuric acid is used for the absorption of hydrocarbons other than methane from illuminating gas. The acid used must be the strongly fuming (Nordhausen) acid, which readily deposits crystals on cooling slightly below the ordinary temperature. It is used, according to the method of analysis employed, either in absorption pipettes charged with glass beads, or on coke-balls introduced, when thoroughly saturated with the fuming acid, into the gas under examination. It is especially active towards hydrocarbons of the ethylene series, but absorbs also those of the benzene and acetylene series. It is usual to assume in analyses of illuminating gas that fuming sulphuric acid absorbs all the hydrocarbons present, but paraffins can often be found in gas which has been submitted to its action. Care must be taken that the acid vapours and reduction products are removed from gas after the absorption of hydrocarbons by fuming sulphuric acid before the amount of the absorption is measured. For this purpose, the gas is treated with potassium hydrate solution before measurement.

Bromine is also used for the absorption of hydrocarbons from illuminating gas. It appears from experiments by Winkler that with the same sample of gas, fuming sulphuric acid gives a rather greater absorption than bromine, so in exact analyses it is preferable to use the former reagent. For rough analyses bromine is useful, as it may be used where water is the confining medium. A nearly saturated aqueous solution of bromine serves every purpose; the bromine vapour must be removed from the gas by potassium hydroxide solution before the amount of absorption is measured. In some cases it is preferable to use a solution of bromine in potassium bromide; this solution can be standardized if required.

Alcohol is used for the determination of the so-called hydrocarbon vapours in illuminating gas according to Bunsen's method. The ordinary absolute (ethyl) alcohol of the manufacturing chemists should be used. The vapours absorbed by alcohol from coal gas consist almost entirely of benzene and its homologues, and are practically identical with those obtained by St. Claire Deville by cooling the gas to − 22° C. The gas that has been agitated with alcohol must be agitated with water (previously saturated with the gas) before the amount of contraction is measured, as otherwise the alcohol vapour contained in it will cause an erroneous reading.

Oxygen is used in the determination of hydrogen, methane, and carbon monoxide by explosion. It must be perfectly pure, and is best prepared by the following method:—A test tube of combustion glass is about one-third filled with dry, pulverized potassium chlorate. The upper end is then drawn out into a long delivery tube, which is bent into the shape shown in Fig. 29. The turned-up end dips under mercury in a trough, and from it inverted test tubes or other receptacles can be filled with the gas in the ordinary way. The end of the test tube containing the potassium chlorate is then gradually heated until the gas is evolved freely, when the heating must be regulated to give as regular a stream of gas as possible, care being taken, by application of heat to the upper part of the molten salt, to prevent the formation of solid crust on the top, which, by preventing the escape of the gas, may cause the shattering of the tube. When the evolution has proceeded for a few minutes, the gas should be collected, care being taken that the receptacles are filled with mercury to the exclusion of bubbles of air. The first test tube of gas collected should be afterwards tested by absorption with potassium pyrogallate. There should remain not more than 0·5 per cent. of gas after the absorption, the residue almost invariably found being carbon monoxide, evolved during the absorption. If the first tube of gas collected satisfies the above condition, the others may be used in analysis

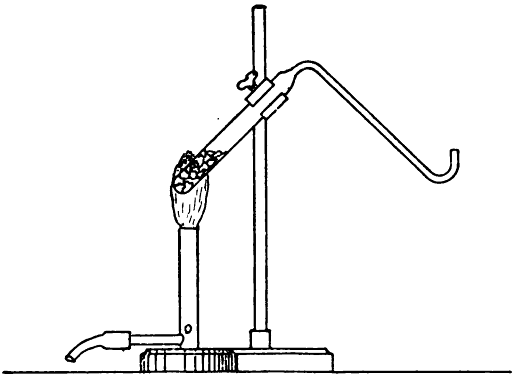

Fig. 29.—Apparatus for preparing oxygen for gas analysis.

as pure oxygen, though, as an additional precaution, the last tube collected is sometimes also tested by absorption with pyrogallate. By the above method, no joints are required in the apparatus, and the chances of the gas being impure are remote.

Hydrogen is sometimes required in gas analysis for the determination of the residual oxygen after the explosion, with excess of oxygen, of the combustible gases in a mixture. It is best prepared electrolytically, being collected from the platinum plate connected to the negative pole of a battery; the electrolyte being water acidulated with dilute sulphuric acid, and the wire to the positive pole of the battery being immersed in zinc amalgam. The hydrogen so evolved is pure, the oxygen produced by the electrolysis of the water going to the zinc, which then combines with the acid to form zinc sulphate. An apparatus for the production of electrolytic hydrogen has been designed by Bunsen, and is obtainable of most makers of chemical apparatus. When hydrogen cannot be made electrolytically, it should be evolved from *pure* zinc or magnesium and dilute sulphuric acid, and purified by passage through a solution of chromic acid contained in absorption bulbs. If, owing to the extreme purity of the materials employed, the gas comes off very sluggishly, the rate of evolution may be quickened by the addition of a drop of solution of platinic chloride to the liquid in the evolution flask. A method for the preparation of both hydrogen and oxygen electrolytically for gas analysis has been devised by A. Ehrenberg.*

Frankland and Ward's Apparatus for Gas Analysis.— For the complete and exact analysis of a sample of gas, a modification of Frankland and Ward's apparatus is now generally used. In these instruments measurements are made of the tension of the gas when expanded to a constant volume, at each stage of the operations. A simple pattern of this apparatus is illustrated in Fig. 30, freed from many of the appurtenances necessary to accurate working, but which do not affect the general principle of it. The tube, A, known as the barometer tube, is about 6 mm. internal diameter and 1,300 mm. in height, graduated in millimetres for a metre from the top. It passes through the water jacket, B, into the iron tube, C, where it is connected to an iron pipe having a right-angled connection leading to the tube, D, and provided below the junction with the iron tap, E, which must be ground accurately into its socket, and must be furnished with a lever about 8 inches in length, so that the tap may be turned with ease. Below the tap, flexible pressure tubing passing through the table connects the pipe to the glass mercury reser-

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* *Zeitschrift. f. Anal. Chem.*, vol. xxvi., p. 226.

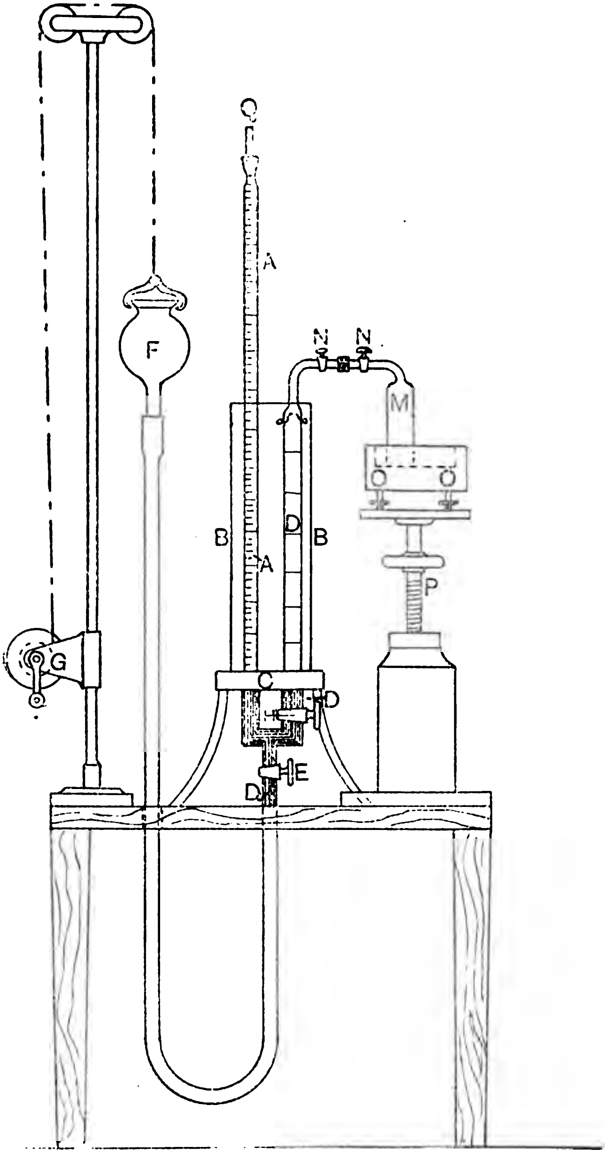

Fig. 30.—Apparatus for the complete analysis of a sample of gas.

A, Barometer tube; B, water jacket; C, iron base; D, measuring tube; E, tap; F, mercury reservoir; G, windlass; H, N, stop-cocks; M, laboratory vessel; O, mercury trough; P, screw; Q, plug.

voir, F, which is supported by catgut passing over small pulleys and winding on the small windlass, G, whereby the reservoir is readily raised and lowered, the table top being cut to permit the passage of the reservoir through it. The iron pipe leading beneath the water jacket to the tube, D, is provided with a separate iron stop-cock, H, so that the tube may be shut off from connection with the barometer tube, A. The measuring tube, D, is about 20 mm. internal diameter and 700 mm. in height, and is graduated into ten parts. The tube merges at its upper end into a capillary, provided with a stop-cock, and connecting with the laboratory vessel, M. This is bell-shaped, and at the apex ends in a capillary. The laboratory vessel can usually be disconnected from the measuring tube, and the portion of the capillary tube attached to it is then provided with a stop-cock, N. Connection is usually made on the horizontal portion of the capillary by means of accurately-fitting steel facets cemented to the glass, and kept in close contact by a screw metal clamp. In some forms of apparatus the capillary is without break, and shortened, being provided merely with one three-way mercury stop-cock. The laboratory vessel is then firmly supported by a clamp, and cleaned by syringing from beneath. The laboratory vessel in all forms of the apparatus dips into a trough, O, containing mercury, the trough being provided with ledges for the support of the vessel in cases where the clamp just mentioned is dispensed with. The support for the trough can be raised or lowered by means of a vertical screw, P, which is held firmly when the required height is attained by means of a screw in the base block. The top of the barometer tube is closed by a well-ground and slightly-greased plug, Q. Through the water jacket, B, which envelopes the greater portion of the barometer tube and the measuring tube, water circulates, being supplied from a cistern kept at a tolerably uniform temperature. An inverted tube forms a water jacket to the upper part of the barometer tube, the water in this also being kept in circulation. A white cardboard screen with a horizontal black strip is arranged to travel up and down on a small pulley at the back of the barometer tube, to facilitate the reading of the mercury level. The readings are made by a telescope with crossed wires. The last few accessories are omitted from the drawing for the sake of clearly showing the more characteristic parts of the apparatus.

Preparation and Calibration of the Apparatus.—To prepare the apparatus for use, the lowered reservoir is filled with mercury, the stop-cocks opened, and the plug removed from the top of the barometer tube. The reservoir is then raised, and the mercury flows through the flexible tube and iron pipe into the barometer and measuring tubes. When it has reached the top of the latter tube, the tap, H, is closed, and the mercury allowed to ascend to the top of the barometer tube. The plug is then inserted, the mercury lowered a trifle, and a drop or two of water is drawn in from the cup round the plug. A drop or two of water is similarly drawn into the measuring tube. With the plug, Q, inserted, the stop-cock, N, closed, and the taps, E and H, open, the mercury is raised and lowered in the tubes several times, in order to remove air clinging to the glass. This air is then expelled from the tops of the tubes. The raising and lowering of the mercury level in the tubes is in all cases effected by raising or lowering the reservoir, F, by means of the windlass, G. The windlass is furnished with a toothed wheel, on which falls a clutch to prevent the cord unwinding from the weight of the reservoir dependent on it.

The measuring tube must now be carefully calibrated, so that the exact volume between any two divisions is known. This is done by filling the tube with water, bringing the mercury to the level of the lowest division, and then by raising the level of the mercury to the next division, forcing out through the capillary tube into a tared flask the volume of water contained in the tube between the two divisions. The temperature of the water in the jacket is observed, and the weight of water in the flask carefully ascertained. From this the content of the tube between the two divisions is calculated. The same operation is repeated at each divisional mark, until the content of the tube between adjacent divisional lines, and from the top mark to the stop-cock at the top of the tube is known accurately. The results are tabulated for reference. The height of mercury in the barometer tube corresponding to each divisional mark on the measuring tube is then carefully found, by the mercury being gradually raised until the top of the meniscus exactly coincides with the mark, when the mercury level in the barometer tube is read and recorded. As the barometer contains moisture, no correction is needed for the tension of aqueous vapour, the temperature in both tubes being the same.

These constants for the apparatus having been found, it is ready for use for an analysis. The laboratory vessel is connected to the measuring tube, and the trough, O, is filled with clean mercury. A little mercury is then driven over from the measuring tube, so as to fill the capillary, and the open end of the laboratory vessel being beneath the mercury in the trough, a bent glass tube, terminating at one end in a fine point, has that arm passed up into the laboratory vessel. The outer arm of the glass tube is attached to a suitable length of rubber tubing. The operator stands with his mouth some inches above the level of the mercury in the trough, and, placing the end of the rubber tube in his mouth, proceeds to suck out the air from the laboratory vessel. When the air is nearly all extracted, care must be taken that the fine end of the glass tube passes up to the entrance to the capillary, and the latter being filled with mercury, the last traces of air can be extracted from the vessel with certainty.

The gas for analysis is introduced into the laboratory vessel from an inverted test tube in the trough, or by bubbling it under the mercury direct into the laboratory vessel; care must be taken that all connections used in the transference of a sample of gas are freed from air before the portion of gas intended for analysis is collected. For the purpose of illustrating the method of conducting an analysis of a complicated mixture, it may be assumed that a sample of coal gas is undergoing examination. About 3 c.c. of the gas is introduced into the laboratory tube, and then drawn over into the measuring tube; the cock, N, is closed, and the mercury column lowered by means of the suspended reservoir, until it is just below the mark at which it is intended to read the tension of the gas. It simplifies the calculation if the same mark is used throughout the analysis, as the results can then be at once calculated to percentages without calculating the absolute volume of the gas used, or making corrections for the different capacities of the tube between different marks. The third mark from the top will be found a convenient one at which to take a reading. The screen is brought so that the lower edge of the black strip is slightly above the level of the mark on the tube, and the mercury is then slowly raised until the top of the meniscus exactly coincides with the mark on the tube, the final adjustment being made under observation through the telescope. The temperature of the water in the jacket is ascertained from an open scale thermometer suspended in it. The readings are independent of atmospheric pressure. The height at which the mercury now stands in the barometer tube is carefully read by the telescope. The height at which the mercury would stand in the barometer tube when the mercury in the measuring tube is at the same mark and under the tension of aqueous vapour only, has already been found and recorded. By deducting the reading now taken from that figure, the pressure exerted by the gas at the temperature observed is found.

Determination of the Carbonic Acid.—About half a cubic centimetre of solution of caustic potash is introduced by means of a pipette with a capillary orifice bent upwards into the laboratory vessel. The gas is then passed back into the laboratory vessel, and the mercury allowed to flow over into that vessel to bring the gas into intimate contact with the reagent. This absorption of carbonic acid is complete in about five minutes. The gas is then drawn back into the measuring tube, care being taken that none of the potash solution passes the stop-cock, N, which must be shut at the precise moment when all the gas has passed. The pressure exerted by the gas after the absorption of carbonic acid, is now found in a similar manner to the pressure of the gas before the absorption. Or for simplifying the calculation, the height of the mercury in the barometer tube, after the absorption, is deducted from the height of the mercury in the barometer tube before the carbonic acid was absorbed from the gas. This gives the pressure due to the carbonic acid in the gas. The pressure due to the total volume of the gas, before the absorption, is known. With constant temperature the volumes are proportional to the pressures they exert, hence the percentage of carbonic acid in the gas may be at once calculated. If the temperature of the water in the jacket has changed, correction must be made for the change of volume caused by the change of temperature.

Determination of the Oxygen.—About half a cubic centimetre of solution of pyrogallic acid is now introduced into the laboratory vessel, and the gas is passed over to the latter, and the mercury allowed to flow into it for fifteen to twenty minutes, when the absorption may be considered complete. The gas is now passed over into the measuring tube, and the difference between the pressure exerted now and at the last reading ascertained. With constant temperature, the difference will be the pressure due to the oxygen in the gas, and the percentage may be calculated from the pressure due to the total volume of the original gas. The solution in the laboratory vessel must now be removed, and the vessel washed and dried. The method by which this is done depends on the type of vessel and the method of support. If it is held firmly by a clamp, air is blown into it, and the mercury trough is lowered and the surface of the mercury cleaned. The vessel is then well syringed inside, and afterwards carefully dried by means of a dry cloth pushed up into the vessel. The drying may be rendered absolute by raising the trough, filling the vessel with mercury, and introducing a few drops of strong sulphuric acid. The laboratory vessel is emptied, and the mercury, after cleansing, again drawn into the vessel. Sulphuric acid should only be introduced to the vessel when the absorption of hydrocarbons by fuming acid is to follow. Even then, after repeated drying of the vessel with a cloth, it is hardly necessary. The operation of washing a laboratory vessel while in position is much facilitated, and the risk of error lessened by the use of a three-way hollow glass tap on the capillary tube, as recommended by Thomas in the *Journal of the Chemical Society* for May, 1879. If the laboratory vessel is detachable, the washing and drying are readily performed, but the small quantity of gas between the stop-cocks is of necessity lost.

Determination of Hydrocarbons absorbable by Sulphuric Acid.—The next determination is that of the hydrocarbons absorbable by fuming sulphuric acid. The gas is passed over into the dried laboratory vessel, and a coke-ball saturated with the fuming acid is passed up by means of a bent platinum wire into the gas The end of the wire outside the vessel should be placed under the surface of the mercury. An hour should be allowed for the absorption, and the coke-ball when removed should fume strongly in the air. If it does not, it should be again saturated with acid, and passed up into the gas for a further period. After the removal of the coke-ball, two or three cubic centimetres of caustic potash solution should be introduced into the vessel, and five minutes allowed for the absorption of acid vapours and reduction products. The gas is then passed into the measuring tube, and the pressure in the barometer tube read. The percentage of hydrocarbons absorbed is calculated in a similar manner to the percentages of carbonic acid and oxygen.

Determination of the Residual Gases.—The residual gases are determined by exploding with oxygen. The measuring tube has near its top two platinum wires fused in the glass, looped externally, and ending about a millimetre apart inside the tube, as in ordinary eudiometers. It is convenient to use only about a third of the volume of the residual gas for the explosion; therefore about two-thirds is blown away through the capillary, and the residue expanded in the measuring tube, and its pressure found. It is then passed back to the laboratory vessel, and from one and a-half times to twice its volume of oxygen added. The pressure exerted by the mixed gases is found by passing them over into the measuring tube; the mercury is then lowered until the gas is under a pressure of only 150 to 200 mm. of mercury, when the tap at the bottom of the measuring tube is turned, shutting it off from the barometer tube. The water is lowered in the jacket until the platinum loops are no longer immersed; the wires from a small induction coil connected to a battery of six bichromate cells, or from some other apparatus for producing a spark, are looped to the platinum wires, and a spark is passed through the gas. The contained gases will unite with a sharp click unless the proportions are very different from those prescribed. The mercury is admitted to the measuring tube, the water in the jacket is brought up to its original level, and the pressure of the gas is ascertained. From this and the previous reading, the contraction caused by the explosion is found. The gas is then passed into the laboratory vessel, and a small quantity of caustic potash solution admitted, to absorb the carbonic acid produced by the explosion. After allowing five minutes for complete absorption to take place, the gas is passed back to the measuring tube, and the pressure it exerts read. The difference between this reading and the preceding one indicates the volume of carbonic acid produced by the explosion. It is then advisable to return the residual gas to the laboratory vessel for the absorption of the excess of oxygen by pyrogallic acid; the volume absorbed being afterwards ascertained from the pressure exerted by the residual gas when returned to the measuring tube. Some operators prefer to determine the excess of oxygen by exploding it with an excess of pure hydrogen, and observing the contraction. The readings taken provide the data for the calculation of the composition of the gas remaining after the absorption of the hydrocarbons, as may be seen from the following, wherein the pressure exerted by a volume of gas is taken to express the volume. The volume of nitrogen is the residue after the absorption of the excess of oxygen, and the percentage may be calculated directly from this and the original volume of gas taken for the explosion determinations. Or, if the excess of oxygen has been exploded with excess of hydrogen, and the contraction found, the amount of the contraction is divided by 3, which gives the volume of the excess of oxygen, and this deducted from the volume of gas prior to the admixture of hydrogen gives the volume of nitrogen, which may then be calculated to percentage on the gas taken for the explosion determination. The other constituents of the gas submitted to explosion with oxygen are hydrogen, methane, and carbonic oxide. Hydrogen on explosion with oxygen leaves no gaseous product, but combines with half its volume of oxygen, therefore the contraction brought about by the explosion of hydrogen with excess of oxygen is 1·5 times the volume of hydrogen present. Methane combines on explosion with excess of oxygen with twice its volume of the latter gas, and there is produced its own volume of carbonic acid, so the contraction will be equivalent to the oxygen consumed, or to twice the volume of methane present. Carbonic oxide on explosion with excess of oxygen unites with half its volume of the latter gas, and the carbonic acid produced is equal to its volume, so the contraction is equal to the volume of oxygen consumed, or to half the volume of carbonic oxide present. Let *h*, *m*, and *c* represent the volumes of hydrogen, methane, and carbonic oxide respectively, and T the total volume of gas, and consequently the sum of h, m, and c. Then the carbonic acid produced will be equal to the united volumes of methane and carbonic oxide, and this is measured by the amount of absorption by potash. Therefore, taking T, the total volume of the gas to be submitted to explosion with oxygen minus the volume of nitrogen present, and deducting the volume of carbonic acid absorbed, $h =$ the volume of hydrogen present, is at once obtained.

The total contraction is equivalent to $1{\cdot}5\,h + 2\,m + 0{\cdot}5\,c$. Let this volume be $=$ C. Let $m + c =$ the volume of carbonic acid absorbed $=$ A. Also we have T, the total volume (minus the volume of nitrogen) $= h + m + c$.

$$\begin{array}{ll}
\text{Now,} & c = 2C - 4m - 3h \\
\text{And also,} & c = A - m \\
\text{Therefore,} & 3c = 4A - 2C + 3h \\
\quad ,, & 3c = 4A - 2C + 3(T - A) \\
\quad ,, & 3c = A - 2C + 3T \\
\text{Or,} & c = T + \frac{A}{3} - \frac{2}{3}C
\end{array}$$

That is, the volume of carbonic oxide is equal to the total volume of gas, added to a third the volume of the absorption by potash, less two-thirds the contraction due to the explosion.

Again, $m = A - c$

Therefore, substituting the value of c

$$m = A - T - \frac{A}{3} + \frac{2}{3}C$$

$$\text{Or,} \qquad m = \frac{2A - 3T + 2C}{3} = \frac{2(A + C)}{3} - T.$$

Or the volume of methane is equal to two-thirds the sum of the volume of the potash absorption and the contraction, less the total volume of gas taken.

The nitrogen having been actually estimated by difference, the percentages of hydrogen, methane, carbonic oxide, and nitrogen in the gas remaining after the absorption of the hydrocarbons, will give a total of exactly 100. But since the residual gas on which these estimations are carried out is only a fraction of the original coal gas, corrections must be made to give the true percentages of these constituents in the gas. The volume of the coal gas had been reduced by the absorption of carbonic acid, oxygen, and hydrocarbons, consequently, if the percentages of these constituents are deducted from 100, we obtain the percentage on the original gas of the residue on which the estimations by explosion were made. The percentage composition of this residue is known, and it only remains to calculate, by proportion, from the percentage of the residue on the original gas, the percentages of hydrogen, methane, carbonic oxide, and nitrogen in the latter. If the calculations have been correctly performed, the sum of the percentages of hydrogen, methane, carbonic oxide, hydrocarbons, carbonic acid, oxygen, and nitrogen will be exactly 100.

Chief Sources of Error.—The chief chances of error in an analysis of coal gas performed in this apparatus lie in incomplete absorption of constituents through not sufficiently prolonged exposure to the reagents, in careless reading of volumes, and in incomplete combustion through the addition of the wrong proportion of oxygen, or too great rarefaction of the gas before the explosion. Many other and large errors may be caused by an apparatus in improper working order, or by neglect to make correction for the effect of change of temperature during the analysis on the volume of the gas. The taps and stop-cocks on the apparatus must fit perfectly, and not allow the escape of gas under pressure, or the ingress of air when the pressure within the apparatus is represented by very few millimetres of mercury. The calibrations must also have been performed with accuracy. When once the apparatus has been brought into thoroughly good working order, an analysis of coal gas, according to the above scheme, can be completed in from three to four hours, and reliable results obtained.

Modifications.—The scheme requires modification under certain conditions. If sulphuretted hydrogen is present in the gas, it would be estimated in the potash absorption together with the carbonic acid. When the percentage of each of these constituents is required, the sulphuretted hydrogen must be absorbed first by an agent which does not absorb carbonic acid. The most useful is manganese peroxide, which is generally applied as a bullet. The bullet is formed by drying the moistened oxide charged into the mould, with the end of a piece of platinum wire passing into the material. The dry bullet should be moistened with syrupy phosphoric acid, to render it non-porous. It should then, according to Lewis T. Wright's recommendation, be saturated with coal gas, by being placed in a stream of the purified gas. The bullet is introduced into, and removed from, the laboratory vessel by means of its attached platinum wire, in the same manner as the coke bullet for the hydrocarbon absorption. At least half an hour should be allowed for the absorption of sulphuretted hydrogen by a manganese peroxide bullet. After the amount of gas absorbed has been found by measurement, and the gas has been returned to the laboratory vessel, the carbonic acid is estimated by caustic potash, in the manner already described. The estimation of the sum of the two constituents by caustic potash on a fresh volume of the gas affords a useful check on the separate estimations, as the difference by the two methods should not be greater than 0·02 per cent.

When the gas undergoing analysis is not coal gas, some modification of the amount given above of oxygen for the explosion may be necessary. The proportions of the gases in the residue reserved for explosion should be approximately found, and the amount of oxygen required may then be calculated by allowing for hydrogen and carbonic oxide their own volume, and for methane nearly three times its volume of oxygen. The pressure of the gas when about to be fired should not exceed 200 mm. If these precautions are neglected, the explosion may be too violent, and the tube be shattered, or the union may be incomplete through imperfect combustion.

Hempel's Apparatus.—An apparatus for the complete analysis of a sample of gas has been devised by Prof. W. Hempel, and yields good results. Since it is of totally different construction to the Frankland and Ward type of apparatus, and space forbids its full description here, students are referred to the inventor's text-book (recently translated into English*) on *Gas Analysis* for particulars of, and the method of working it.

Elliot's Apparatus.—The number of forms of apparatus for the rapid approximate or partial analysis of a sample of gas is legion, and only a few of the more common can be mentioned here. Some are especially serviceable for the partial analysis of generator and furnace gases. One of the most generally useful types of apparatus is that devised by Elliot,† which is illustrated in Fig. 31. A is a measuring tube, containing exactly 100 c.c. between the zero point at C and the mark *d*, close to the stop-cock, *e*. The tube is graduated between these two points into divisions of 0·1 c.c. The tube is closed at its lower end by a cork, perforated to receive a piece of glass tubing, which serves to connect it by rubber tubing to the outlet tube of the bottle, F, which in shape resembles an aspirating bottle. The upper part of A is a thick-walled capillary, which bends at right angles to the wide portion of A, and has in the horizontal portion the stop-cock, *e*. B is a tube containing 120 c.c. between the stop-cock, H, and the mark, *g*. From the capillary upper part, just below H, proceeds the capillary tube, *k*, at right angles to the stem, B. This (*k*) is connected by means of a short piece of sound rubber tubing to the capillary tube of A. Above the stop-cock, H, the thick-walled capillary tube tapers externally, and is ground to fit into the funnel-shaped vessel, M, which contains 25 c.c. to a mark near its top, when fitted on to the ground top of B. The lower end of B is fitted with a perforated cork, through which passes the glass tube, N, which has in its horizontal arm the three-way stopcock, O. The rubber tube, P, connects N to the bottle, R, which is similar to F. The stopcock, O, is so arranged that it gives either a free passage between N and P, or a passage between one of these and the external air, through an orifice in the bottom of the stem.

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* *Methods of Gas Analysis*, by Dr. W. Hempel, translated by L. M. Dennis. London, 1892.

† *Annals of the New York Academy of Sciences*, vol. ii., No. 12.

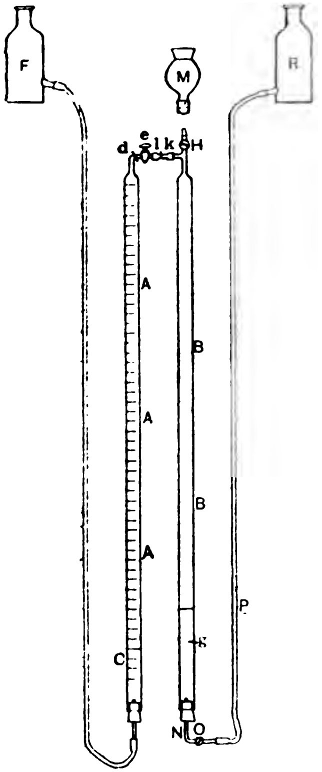

Fig. 31.—Elliot's gas analysis apparatus.

A, Measuring tube; C, zero; *d*, 100 c.c. mark; *e*, stop-cock; F, bottle; B, laboratory tube; H, stop-cock; *g*, 120 c.c. mark; *k*, capillary tube; M, funnel; N, tube with a three-way stop-cock, O; P, tube connecting N with R; R, bottle; *l*, junction of capillaries.

The bottles, R and F, are filled with water, and from them the tubes, A and B, previously connected at *l*, are filled. When these are filled with water, the cocks, H and *e*, are shut, and M being removed, the top of B is connected to the vessel containing the gas for analysis, the connecting tube having been previously freed from air. On opening the cock, H, and lowering the bottle, R, the gas is drawn into B, and H is closed when the gas reaches *g*. By raising R, lowering F, and opening the cock, *e*, the gas is drawn over into A. The surface of the water in F is brought level with the zero mark, C, and by lowering R the water in A is brought to that mark. The stopcock, *e*, is closed, and the tube, A, then contains 100 c.c. of gas at the atmospheric temperature and pressure, which should be ascertained and recorded. The aining in B is driven off through H, and the funnel, M, ted to the top of the tube. By raising F, lowering R, and opening *e*, the gas is drawn over into B. When all has passed over, *e* is closed, and the funnel, M, is filled up to the mark with solution of caustic potash. The water level in B is brought as low as possible by means of R, and the stop-cock, O, is then closed to N. From M the potash is slowly run into B, care being taken to leave a small quantity in M, though, if the absorption appears to be very great, M may be replenished with more solution of potash. Ten minutes at least should be allowed for the absorption; the gas is then passed back into A, and the volume measured as before; the diminution in volume represents the carbonic acid absorbed, provided temperature and pressure have remained constant. The gas is then drawn back to B, and solution of pyrogallic acid run in through M, followed by a slight excess of caustic potash. About twenty minutes should be allowed for the absorption; the gas is then run back to A and remeasured; the diminution in volume since the last measurement represents, provided the atmospheric conditions are unchanged, the volume of oxygen in the gas. The tube, B, is then thoroughly washed out through M with water, and refilled with clean water; the gas is then drawn over as before, and bromine water admitted from M. The gas in B should be distinctly tinged with bromine vapour, but care must be taken that the vapour does not cause pressure sufficient to drive some of the gas out when H is opened. This may be avoided by lowering R and opening O, so that there is a slightly reduced pressure in B when H is opened. Ten minutes should be allowed for the absorption, when H should be opened, and dilute solution of caustic potash admitted from M to absorb the bromine vapour. The gas is then passed back to A and measured. The diminution since the last measurement is the volume of "hydrocarbons" in the gas. The tube, B, is again washed out, and refilled with water; the gas is drawn over to B, and solution of cuprous chloride in hydrochloric acid slowly admitted through M, the water at the lower part of B being run out by means of O, until it is entirely replaced by cuprous chloride solution from M. At least half an hour should be allowed for this absorption; the cuprous chloride solution may be run out through O for use again, water, and finally dilute solution of caustic potash, being admitted through M in order to absorb acid vapours. The gas is then passed over into A, and measured; the diminution in volume gives the volume of carbonic oxide in the gas. The percentages of carbonic acid, oxygen, "hydrocarbons," and carbonic oxide have now been found, and this is as much as can be done with the apparatus as described. This information is often sufficient for judging the quality and approximate heating value of producer and water gas, or for the control of exit furnace gas, and may occasionally be of use with respect to illuminating gas of various kinds. The remarks which will be made later (p. 185) with regard to the analysis of gas over water, of course apply to analyses made with the ordinary form of this apparatus, though perhaps with less force than to other appliances where the gas is frequently subjected to a drastic washing. It must be borne in mind, however, that with every care in working, and with correction of volume for temperature and pressure, contact with water will introduce an error in the analysis of nearly all gases, especially those rich in carbonic acid, oxygen, or "hydrocarbons."

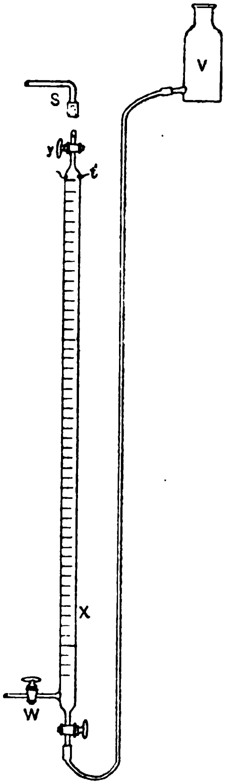

Fig. 32.

Explosion tube of Elliot's gas analysis apparatus.

X, Zero mark; *y*, stop-cock; *t t'*, platinum wires; W, stop-cock; V, bottle; S, thick-walled capillary.

By the aid of an additional tube for explosions, a complete analysis may be made with Elliot's apparatus. This tube is illustrated in Fig. 32, and contains 100 c.c. between the zero mark, X, and the stop-cock, *y*, and is calibrated between those points into tenths of a cubic centimetre. The top is ground similarly to the top of B (Fig. 31), and fits either the funnel, M, or the conical ground mouth of the thick-walled capillary, S. *t t'* are two platinum wires fused into the glass as in ordinary eudiometers, and W is a stop-cock on a side capillary through which oxygen or hydrogen may be introduced for the explosions. V is a bottle connected by rubber tubing to the bottom of the burette, and is used as the bottles, F and R (Fig. 31). The two tubes in the apparatus shown in Fig. 31 are disconnected at *l*, and by means of S, and a short piece of sound rubber tubing, about 20 c.c. of the residual gas from the absorptions is drawn into the explosion burette, which had previously been completely filled with water from V. The cock, *y*, is shut, and the gas measured under atmospheric pressure by levelling with the bottle, V. Rather more than the same volume of oxygen should be introduced through W, and the total volume of gas in the burette carefully measured under atmospheric pressure. By means of lowering, V, the pressure is reduced as much as possible in the burette, and a spark is then passed through the mixed gases by the platinum wires, $t\,t'$. The water is allowed to flow from V into the burette, and after allowing about a quarter of an hour for the cooling of the gas, the volume is measured, and the contraction brought about by the combination ascertained. Solution of caustic potash is then run in by aid of the funnel, M, and after allowing time for the absorption, the gas is remeasured, and the amount absorbed is the volume of carbonic acid formed by the explosion. These data suffice for the calculation of the percentages of hydrogen, methane, and nitrogen in the mixture; but a useful check is afforded on the working by estimating the nitrogen as the residue left, after absorbing the excess of oxygen by potassium pyrogallate, or after estimation of the excess of oxygen, by explosion with hydrogen. If the analysis has been correctly performed, the amount of nitrogen so found should agree with that calculated from the results of the first explosion.

Then, from the data furnished on p. 172, the proportions of the three gases in the mixture introduced for analysis into the explosion tube can be calculated, thus:—

Let T = the volume of gas taken, and h, m, and n the volumes of hydrogen, methane, and nitrogen in it respectively. Then the contraction on explosion will be equal to $1{\cdot}5h + 2m$. The carbonic acid formed will be equal to m, and, consequently, gives directly the quantity of methane in the mixture. Substituting this value for m in the contraction equation, the volume of hydrogen present is found to be the difference between the amount of contraction and twice the amount of carbonic acid formed divided by $1{\cdot}5$; or if C = the contraction and A = the carbonic acid produced by the explosion, then the volume of hydrogen $= h = \frac{C - 2A}{1{\cdot}5}$, or $\frac{2C - 4A}{3}$. The nitrogen is, of course, the remainder, or $n = T - \frac{2C - 4A}{3} - A = T - \frac{2C}{3} + \frac{A}{3}$.

The percentage composition of the residual gas taken for the explosion is now known, and from the proportion this residual gas bears to the original gas, the percentages of hydrogen, methane, and nitrogen in the original gas are calculated.

If the analyses are performed with reasonable rapidity in a room not subject to sudden changes of temperature, and with the reagents and water employed at the room temperature, it will often be found that the measurements throughout one analysis can all be made at one temperature, and thus no correction is requisite. Various forms of apparatus resembling Elliot's in many respects, but substituting mercury for water as the containing liquid, have been proposed, and give correspondingly better results, but the information already given in this chapter will enable the student to use any one of them that may fall into his hands, provided he bears in mind the few cardinal principles of gas analysis.

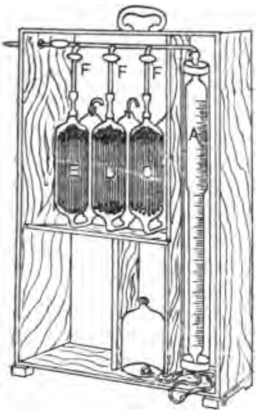

Fig. 33.—Orsat-Muencke's gas analysis apparatus.

A, Graduated tube; C, vessel with caustic potash solution; D, vessel with potassium pyrogallate solution; E, vessel with acid solution of cuprous chloride; F, capillary tube.

Orsat-Muencke's Apparatus.—A useful apparatus for the partial analysis of producer and water gas, or chimney gases, is the Orsat-Muencke, which has the advantage of being portable and entirely self-contained. It is illustrated in Fig. 33, the wooden case in which it is mounted having a back and front sliding in grooves, forming a dust-tight case when closed, and rendering the apparatus suitable for being carried about a works. The back and front of the case are removed during use, and the gas for analysis is measured in the graduated tube, A, contained in a water jacket, the level being regulated by means of water in the bottle which is attached by flexible tubing to the lower end of A. The three vessels, C, D, and E, contain $\frac{1}{8}$-inch glass tubing of suitable length, so as to present a large surface. They are connected to the three branches from the thick-walled capillary tube, F, each branch being furnished with a well-fitting stop-cock, as is also the end of F most distant from A. The first vessel, C, is charged with solution of caustic potash, the second, D, with solution of potassium pyrogallate, and the third, E, with acid solution of cuprous chloride, the small glass tubes in this vessel containing spirals of copper wire to preserve the cuprous state of the salt. The analysis is conducted by driving the gas into each of these vessels in turn, and measuring the absorption in each case. The glass tubes present a large surface wetted with the absorbing liquid to contact with the gas, and thus the absorption takes place with considerable rapidity. The liquid expelled from the vessel by the gas passes, by means of the connecting capillary, into the hinder branch of the vessel, which is similar in shape to the front, but is either open at the top, or better, connected to a small bladder or other means of excluding air, and of furnishing pressure to drive the liquid back into the foremost part of the vessel if required. The gas is admitted to each vessel by opening the stop-cock connecting it to the tube, F, and raising the bottle connected with A, the other stop-cocks being of course closed. After passing into the cuprous chloride solution the gas should be passed into the caustic potash vessel before it is measured. With a little practice considerable facility in the working of this apparatus may be acquired, and an analysis made with rapidity and tolerable accuracy. Each operator will generally modify the apparatus slightly to suit his own views and method of working. The need for a fresh vessel for cuprous chloride solution each time the copper wire becomes consumed is avoided by having the top of this vessel made as a perforated stopper, ground air-tight into the body of the vessel. By removing the stopper when the copper is exhausted, the glass tubes may be taken out, charged with fresh copper wire and replaced, and the vessel becomes again ready for use. In the original form of the apparatus the tubes could not be taken out to be recharged with copper, and the vessel when once exhausted had to be replaced by a new one. The introduction of the stopper, which also facilitates washing, is due to C. Heintz.

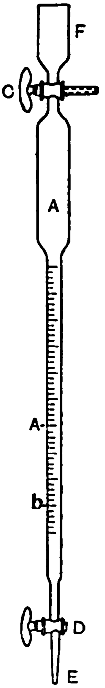

Fig. 34.—Bunte burette.

A, Body; *b*, zero mark; C, stop-cock; D, lower stop-cock; E, nozzle of capillary; F, cup.

Bunte's Burette.—Various forms and modifications of Lunge's nitrometer are used for the partial analysis of gas, but do not require special notice here. The simplest piece of gas analysis apparatus in common use is the Bunte burette, shown in Fig. 34. The body A of the burette is calibrated in divisions of 0·2 or 0·1 c.c., and contains exactly 100 c.c. between the zero mark at *b* and the upper stop-cock, C. The tube is also graduated downwards from the zero mark for 10 c.c., the mark for the latter volume being only a short distance above the lower stop-cock, D. The thick-walled capillary tapers slightly to the nozzle, E. The cup, F, contains about 30 c.c., and has generally two marks, one at the level of 20 c.c., and the other at the level of 25 c.c. from the stop-cock, C. For most purposes one mark on the cup suffices. The upper stop-cock is generally a three-way one, giving communication either between the cup, F, and the body of the burette, A, or between either of these and the exterior through the stem of C being perforated lengthwise. D is a simple stop-cock in the capillary leading to the orifice, E. D and C must be thoroughly well ground in, and not leak when the pressure within the burette is reduced to half the atmospheric. It generally is advisable to have these stop-cocks of Greiner and Friedrich's pattern, illustrated for a two-way cock in Fig. 35, as the liability to leakage is thus greatly lessened. The burette is filled with the sample of gas for analysis in various ways, according to the source from which it is taken. For gas issuing at pressure from a tap, it is sufficient to connect the tap with the nozzle of the burette by a short piece of flexible tubing, and to allow the gas to stream through the burette for some few minutes, holding the nozzle of the burette uppermost to facilitate the displacement of the air. The stop-cocks are turned so as to shut off the interior of the burette from external communication as soon as the burette is filled with gas, the time taken to fill it varying with the pressure at which the gas issues from the supply tap. If the sample has to be taken from a flue or shaft, a piece of platinum tubing, 3 to 5 feet in length, protected by being fixed within a piece of $\frac{3}{4}$-inch iron gas piping, perforated in several places near the end to admit the gas to the platinum tube, is connected by flexible tubing to the barrel of the stop-cock, C, of the burette. The nozzle of the burette is connected to an aspirator, the burette having been previously filled with water if the supply of gas is limited. The free end of the platinum tubing is thrust with its protective casing into the stream of gas, the orifice through which it enters the flue is plugged with clay round the gas piping; the tap, C, of the burette is turned so as to open the passage through the stem to the burette, D is opened, and the aspirator is set at work. When the air or water in A is completely displaced by gas, the cocks, D and C, are shut, and the burette is disconnected from the tube and aspirator. If a small sample of gas only is avail-

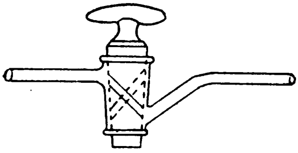
Fig. 35.—Greiner and Friedrich's stop-cock.

able, it may be drawn into the burette through the stem of the cock, C, the burette having been previously filled with water, which is run out through E to admit the gas. When the sample is taken, the stem of the cock, C, may be closed up by slipping over it a short piece of rubber tubing, plugged by a piece of glass rod. The burette is supported in a cork-lined screw clamp in a vertical position, and allowed to remain for a quarter of an hour for the gas within to attain the temperature of the room. The cup, F, is then filled with water, the cock, C, opened, and some of the water will flow into the burette; if the gas was cold when admitted, only a few drops may enter. In any case there will be sufficient to fill the capillary tube below the cock, D, which is done by turning on that cock for a moment. A piece of rubber tubing of suitable diameter is connected to a water bottle fixed a few feet above the top of the burette. The flow of water is regulated by a spring clip on the tube a few inches from its free end. While the water is flowing from it, the end of the tube is pressed over the nozzle, E, of the burette, the cock, D, is turned on, and the water allowed to rise in the burette to the zero mark. If possible, the exact level of the zero mark is attained, but if the water stands at some mark near it, the level is carefully read, and correction afterwards made for the difference between the actual volume of gas and 100 c.c. The reading should be made with the cup filled exactly to one of the marks on it, and all subsequent readings should be made with the water at the same level in the cup. The cock, C, is turned off, and a piece of flexible tubing, connected through a Wolff's bottle to a vacuum pump, is attached to the nozzle, E, the tap, D, is turned, and the water in the burette is sucked out until the level stands only a few millimetres above the cock, D, which is then shut off. A small cup or a porcelain crucible is nearly filled with solution of caustic potash, and the nozzle, E, is immersed in the solution. The cock, D, is turned on, and the solution flows up into the burette. When it ceases to rise, D is closed, and the burette is taken from the supporting clamp, and while held by the nozzle and the cup, is shaken so as to bring the contained liquid intimately in contact with the gas. After agitation for a few minutes, the burette is returned to its stand, the cup, F, is filled with water, and the cock, C, is opened. Throughout the shifting and agitation of the burette, care should be taken to avoid as far as possible the handling of the body of it, that the warmth of the hand may not affect the volume of the gas. With the proper head of water in the cup, F, the level of the water in the burette is read off, and the diminution (in cubic centimetres) of the volume of the gas, since the initial reading, gives the percentage of carbonic acid (plus sulphuretted hydrogen, if present) in the gas. The atmospheric temperature should be observed at the time of each reading, on a thermometer suspended near the burette, and the necessity for correction of volume for changes of temperature will be avoided if a room of equable temperature can be used for the analysis. The top cock, C, is then shut, and the liquid partially drawn from the burette, and some freshly-made solution of pyrogallic acid introduced in the same manner as the solution of potash, and followed by more potash if necessary. Agitate as before, but for a rather longer time, and read. With similar precautions, the absorption, since the preceding reading, represents the percentage of oxygen in the gas. The solution is entirely removed from the burette by alternate suction and admission of water from F, and bromine water is then passed up into the burette. The absorption of the hydrocarbons takes place with tolerable rapidity; care must be taken that the bromine vapour does not cause a greater pressure than the atmospheric within the burette. If this greater pressure is suspected, the stop-cock, D, should be opened with the nozzle, E, beneath the surface of water, and the gas within will be brought to the atmospheric pressure by the inflow or escape of liquid. C may then be opened in the usual manner, but dilute solution of potash should be run through the burette from the cup, F, in order to remove bromine vapour, before the reading is made. The diminution in volume of the gas since the preceding reading gives the percentage of "hydrocarbons" present. The contained liquid being completely removed as before, acid solution of cuprous chloride is run up into the burette, which is then agitated at intervals during the succeeding half-hour, more cuprous chloride solution being admitted if the absorption is at all considerable. The cuprous chloride is run out, and the acid vapours thoroughly washed from the burette before the reading is made. The diminution in volume since the preceding reading gives the percentage of carbonic oxide in the gas. The Bunte burette in its simple form admits only of the estimation (approximately) of carbonic acid, oxygen, "hydrocarbons," and carbonic oxide; a portion of the residual gas may, however, be driven out through the stem of C to an eudiometer, and exploded with oxygen in the ordinary manner. If a vacuum pump is not available, suction may be applied by the mouth, with the intervention of a Wolff's bottle between the burette and the mouthpiece to retain the liquid withdrawn from the burette, but it requires some little practice to suck out 30 or 40 c.c. from a burette holding about 115 c.c., and this would have to be done in analyses of some kinds of gases—for instance, rich carburetted water gas. Therefore, a good vacuum pump is a great convenience. The Bunte burette is occasionally made with a water jacket to the tube between the two stop-cocks, but it becomes rather cumbersome when so made. If the analysis cannot be carried out in a room of equable temperature, and with the precautions already suggested, the burette may be suspended in a tall glass jar filled with water to the level of the top stop-cock for a minute or so before, and whilst each reading is made. The water in the jar can readily be kept of constant temperature.

Degree of Accuracy of Results.—The forms of apparatus in more common use for the analysis of gas having now been briefly described, it may be well to offer a few remarks on the degree of accuracy which may be expected in general working. For a complete analysis of all ordinary gaseous mixtures, the improved forms of the Frankland and Ward apparatus give the best results, and the degree of accuracy attained practically rests solely with the operator. Next come other forms of apparatus in which mercury is the containing fluid, and unless inherently defective in construction, they likewise yield results dependent almost wholly on the care and skill of the operator. A considerable step downward is taken when mercury is replaced by water. Water absorbs all gases to a greater or less extent, and though the solubility of many of the more common gases, such as hydrogen and nitrogen, is practically *nil*, yet other and often important constituents of a gaseous mixture are readily dissolved. The following table gives approximately the volumes of gases dissolved by 1,000 c.c. of pure water at 20° C. and under 760 mm. pressure; the figures are from determinations by Bunsen or Pauli:—

Gas.	Volume absorbed.
Hydrogen,	19 c.c.
Nitrogen,	14 ,,
Oxygen,	29 ,,
Methane,	35 ,,
Carbonic oxide,	23 ,,
Carbonic acid,	900 ,,
Ethylene,	150 ,,
Acetylene,	950 ,,
Sulphuretted hydrogen,	2,910 ,,
Ammonia,	740,000 ,,

From these figures it will be gathered that a mixture of the first five gases on the list may be analysed without great error over water. To attempt to estimate ammonia over water would manifestly be absurd, and the cases of sulphuretted hydrogen and carbon dioxide do not appear far removed from the same category. In illuminating gases these two gases are present in only small quantities, and in accordance with the doctrine of partial pressures so well enunciated by Ostwald, their estimation may be performed with some degree of precision over water. The error increases with the volume of carbonic acid and sulphuretted hydrogen present, especially in instruments where the gas is freely washed or agitated with water. Hence such instruments may be expected to give too low a result for the absorption of such gases. With illuminating gas, especially that of high candle power, the error in this direction is often more than counterbalanced by the condensation or absorption of hydrocarbon vapours by the solution of potash used for the absorption of carbonic acid. Thus the author found that with 25-candle gas, the estimation of carbonic acid by agitation with solution of potash gave, pretty consistently, results 0·8 per cent. too high, when from 2 to 4 per cent. of carbonic acid was present in the sample. An inexperienced operator, with a simple gas burette, often finds 1·0 to 1·5 per cent. of carbonic acid in perfectly purified coal gas. When it is required to estimate carbonic acid or sulphuretted hydrogen accurately, other methods must be adopted. The estimation of oxygen presents no great difficulty, and if the pyrogallic acid be freshly dissolved, and sufficient time allowed for the absorption, it should be correct. The "hydrocarbons" are generally underestimated in an analysis performed over water. As already stated, bromine gives a slightly lower result than fuming sulphuric acid. If it is desired to separate the "hydrocarbon vapours" of illuminating gas, it should be agitated with absolute alcohol prior to the absorption of other constituents, the alcohol vapour being afterwards washed out with water. The absorption of carbon monoxide is complete if sufficient time is allowed, and the gas is finally agitated with cuprous chloride solution that has not been previously used.

It has often been proposed to substitute other confining liquids for water or mercury. One proposal that has been put to the test is to use water saturated with the gas under analysis at the time. This gives good results, if one kind of gas only is likely to require analysis, and if it is not of too mixed a composition; in other cases so many saturated solutions would be required that the process would become greatly complicated. Prof. Hempel strongly recommends the use of reagents saturated with the gaseous mixture on which they will be used in an analysis. A. H. Allen suggests brine in place of pure water in instruments where mercury is not used.* Dr. A. Fajaus has used petroleum as the confining liquid with excellent results. Petroleum boiling at 195° to 200° C. is, however, used by H. Hassenpflug for the absorption of gaseous paraffins other than methane.*

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* *Journ. Soc. Chem. Ind.*, vol. iv., p. 180.

Estimation of Ammonia.—The accurate estimation of certain important constituents of crude coal gas must next be considered. Of these, ammonia is the one that is first removed from the gas on the works, and the tests for it may be enumerated first here, though the Metropolitan Referees rightly adopt a different order of testing the purified gas. Ammonia is detected qualitatively, if present in quantities of not less than 2 grains per 100 cubic feet of gas, by allowing the gas to stream for a minute on to a moistened slip of turmeric paper. If more than about that quantity of ammonia is present, the turmeric paper will become brown. The rapidity with which the turmeric paper changes colour gives a rough indication of the amount of ammonia present in gas, and may be used for this purpose on the outlets of scrubbers. Turmeric paper is prepared by immersing bibulous paper in tincture of turmeric. The tincture for the purpose may be made by extracting the bruised turmeric root with boiling alcohol, or by allowing alcohol to stand over the bruised root for some days. The quantity of ammonia in gas may be determined by passing a measured volume of the gas through standard sulphuric acid, and afterwards estimating the free acid remaining by titration with standard alkali. For gas-works purposes it is convenient to use the standard acid of the strength prescribed by the Metropolitan Gas Referees for the testing stations under their control. The instructions of the Referees for the preparation of the standard acid and standard alkali run as follows:—

> "Measure a gallon of distilled water into a clean earthenware jar or other suitable vessel. Add to this 94 septems of pure concentrated sulphuric acid and mix thoroughly. Take exactly 50 septems of the liquid and precipitate it with barium chloride in the manner prescribed for the sulphur test. The weight of barium sulphate which 50 septems of the test-acid should yield is 13·8 grains. The weight obtained with the dilute acid prepared as above will be somewhat greater, unless the sulphuric acid used had a specific gravity below 1·84. Add now to the diluted acid a measured quantity of water, which is to be found by subtracting 13·8 from the weight of barium sulphate obtained in the experiment, and multiplying the difference by 726. The resulting number is the number of septems of water to be added. If these operations have been accurately performed, a second precipitation and weighing of the barium sulphate obtainable from 50 septems of the test-acid will give nearly the correct number of 13·8 grains. If the weight exceeds 13·9 grains, or falls below 13·7 grains, more water or sulphuric acid must be added, and fresh trials made until the weight falls within these limits. The test-acid thus prepared should be transferred at once to stoppered bottles which have been well drained, and are duly labelled.

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* *Repert. Anal. Chem.*, 1882, p. 49.

"To prepare the standard solution of ammonia, measure out as before a gallon of distilled water, and mix with it 50 septems of strong solution of ammonia (sp. gr. 0·88). Try whether 100 septems of the test-alkali thus prepared will neutralize 25 of the test-acid, proceeding according to the directions given subsequently as to the mode of testing. If the acid is just neutralized by the last few drops, the test-alkali is of the required strength; but if not, small additional quantities of water or of strong ammonia solution must be added, and fresh trials made, until the proper strength has been attained. The bottles in which the solution is stored should be filled nearly full, and well stoppered."

These solutions are of a convenient strength for the estimation of the small quantities of ammonia present in purified gas, when a considerable volume of gas is used for the test. By using a smaller volume of gas, and by taking more than the quantity of standard acid prescribed by the Referees for the test, there is ample margin for the estimation of the ammonia in crude gas by these standard solutions. For testing the purified gas, a glass cylinder of the pattern shown in Fig. 36, and charged with glass beads, is used to contain the standard acid. According to the instructions of the Gas Referees, the mode of testing is as follows:—

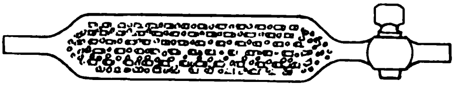

Fig. 36.—Apparatus for determining ammonia in gas.

"Take 50 septems of the test-acid (which is greatly in excess of any quantity of ammonia likely to be found in the gas) and pour it into the glass cylinder, so as to well wet the whole interior surface, and also the glass beads. Connect one terminal tube of the cylinder with the gas supply, and the other with the meter, and make the gas pass at the rate of about half a cubic foot per hour. Any ammonia that is in the gas will be arrested by the sulphuric acid, and a portion of the acid (varying with the quantity of ammonia in the gas) will be neutralized thereby. At the end of each period of testing, wash out the glass cylinder and its contents with distilled water, and collect the washings in a glass vessel. Transfer one-half of this liquid to a separate glass vessel, and add a quantity of a neutral solution of hæmatoxylin, or litmus, just sufficient to colour the liquid. Then pour into the burette 100 septems of the test-alkali, and gradually drop this solution into the measured quantity of the washings collected, stirring constantly. As soon as the colour changes (indicating that the whole of the sulphuric acid has been neutralized) read off the quantity of liquid remaining in the burette. To find the number of grains of ammonia in 100 cubic feet of the gas, multiply by 2 the number of septems of test-alkali remaining in the burette, and move the decimal point one place to the left. The remaining half of the liquid is to be preserved in a bottle, duly labelled, for a week."

The statutory test extends over as nearly as possible twenty hours, during which time 10 cubic feet of gas is passed. The passage of this volume of gas is assumed for the method of calculating the results given by the Referees. The instructions are throughout so framed and worded that they may be readily comprehended and carried out by those unfamiliar with chemistry and the ordinary operations of chemical analysis. Modifications of the exact method prescribed by the Referees will suggest themselves to a chemist who may wish to adapt the test to special requirements about a gas works, and the author merely tenders the following suggestions to the less experienced hands on whom the estimation of ammonia in partially purified gas may at some time fall. Invariably use a carefully-checked pipette to measure out the 50 septems (or other volume) of standard acid. It is convenient to make up the acid washings to a decigallon in a measuring flask of that capacity, and to use half a decigallon for the titration. The 100 septem burette should be carefully calibrated. It is convenient to have it graduated upwards—that is to say, the lowest mark 0, and the highest 100. Where crude or very slightly washed gas is being examined, a 2- or 3-gallon aspirating bottle will generally be substitued for the meter, for other reasons as well as the convenience of testing on a small volume of gas. Absorption bulbs or a bubbling tube may then be substituted for the rather cumbrous cylinder prescribed by the Referees, and the whole of the acid and washings taken for the titration. The calculation of the quantity of ammonia present is simple; the facts to be remembered are that 25 septems of the standard acid neutralize 1 grain of ammonia, and 100 septems of the standard ammonia solution contain 1 grain of ammonia. If an aspirator is used, the volume of water delivered (and consequently of gas aspirated) should be measured in fluid ounces (160 = 1 gallon); then the number of ounces gives the number of one-thousandth parts of a cubic foot of gas aspirated, and the calculation of the amount of ammonia into the customary form of the number of grains per 100 cubic feet of gas is simple. A small error is of course introduced, owing to the volume of gas being measured after the abstraction of the ammonia from it, but it is quite negligible except for crude or nearly crude gas. Correction of the volume of gas may, however, be made if thought desirable. One grain of ammonia at 760 mm. and 15·5° C. occupies a volume of about 0·00318 cubic foot. This figure may also be used for calculating the percentage by volume of ammonia in gas.

Estimation of Sulphuretted Hydrogen.— Sulphuretted hydrogen in gas is detected by the aid of slips of paper moistened with a solution of basic lead acetate. The Acts of Parliament require gas supplied in London to be wholly free from sulphuretted hydrogen, and the Referees prescribe the following as a test for the impurity:—

> "The gas shall be passed, as it leaves the service pipe, through an apparatus in which are suspended slips of bibulous paper impregnated with basic acetate of lead.
>
> "The test-paper from which these slips are cut is to be prepared from time to time by moistening sheets of bibulous paper with a solution of 1 part of sugar of lead in 8 or 9 parts of water, and holding each sheet while still damp over the surface of a strong solution of ammonia for a few moments. As the paper dries all free ammonia escapes.
>
> "If any discoloration of the slip of test-paper is found to have taken place, this is to be held conclusive as to the presence of sulphuretted hydrogen in the gas. Fresh test-slips are to be placed in the apparatus every day.
>
> "In the event of any impurity being discovered, one of the test-slips shall be placed in a stoppered bottle and kept in the dark at the testing place; the remaining slips shall be forwarded with the daily report."

The gas passes through the test-box in which the slips of "lead paper" are suspended on its way to the tube for the ammonia test, hence the paper is subjected to 10 cubic feet of gas passing through the box at the rate of half a cubic foot per hour. According to tests made by one (A. Vernon Harcourt) of the Gas Referees, "lead paper," prepared according to the above directions, will become tinged, especially at the edges, of a faint brown colour, if immersed for twenty-four hours in gas containing 0·001 per cent. by volume of sulphuretted hydrogen, light being excluded from the gas during the test.

The delicacy of well-prepared "lead paper" as a test for sulphuretted hydrogen has long been acknowledged, and the Referees have not made the test so stringent as the paper admits. This is a great advantage to gas engineers, as by using a more exacting form of the test than that adopted by the Referees, they can be absolutely certain that gas is sufficiently clean to pass the trial at the official testing stations. For works' use, the "lead papers" may be made by dipping bibulous paper in a saturated solution of lead acetate, and drying and storing them over a few lumps of sesquicarbonate of ammonia. Before use, the papers should be moistened in clean water, and strips placed in a small box through which the gas passes. The gas should issue from a small orifice at high pressure, and be allowed to impinge directly on to the paper. The delicacy of the test is much enhanced by the use of moistened paper, and the direct impingement of a strong stream of gas, and the slightest trace of sulphuretted hydrogen will not escape detection. Gas that complies with the Referees' requirements must be to all intents and purposes free from sulphuretted hydrogen, and the margin allowed, though very slight, is a great convenience to the manufacturers.

"Lead papers" are serviceable on gas works to indicate the amount of work, as regards the absorption of sulphuretted hydrogen, a purifying vessel is doing. They rapidly turn brown if exposed to a stream of gas containing more than a mere trace of sulphuretted hydrogen. There are several methods for the estimation of the amount of sulphuretted hydrogen in coal gas. Only one or two of the most generally useful need here be mentioned. For the rapid and moderately exact determination of sulphuretted hydrogen, Harcourt's colour test leaves little to be desired for works' use. The description of this test will be given when the other sulphur compounds in gas are treated of, as with slight modification it is applicable, and is, indeed, more generally used for the estimation of carbon disulphide. Harcourt's test is most useful for partially purified gas containing not more than about 50 grains of sulphuretted hydrogen per 100 cubic feet, though it can be used for more foul gas.

The most accurate method of determining the amount of sulphuretted hydrogen in coal gas is that devised by Lewis T. Wright,* based on a method recommended by C. R. Fresenius.† By the latter's plan the sulphuretted hydrogen is absorbed from the dried gas in weighed U-tubes, packed as to five-sixths of their length with pumice on which sulphate of copper has been deposited, and for the remaining sixth with calcium chloride. The pumice is prepared by placing small pieces in a saturated solution of copper sulphate, driving off the moisture by heat, and maintaining the whole at a temperature of 150° to 160° C. for four hours. The volume of gas passed through the tube is measured, and the increase in weight of the U-tubes gives the amount of sulphuretted hydrogen absorbed. Fresenius lays special stress on the drying of the copper sulphate on pumice at the temperature stated, since when dried at a lower temperature it absorbs less sulphuretted hydrogen, and when dried at a higher temperature it effects decomposition of that gas, sulphur dioxide being produced, and carried off in the stream of gas. Lewis Wright takes exception to the use of copper sulphate dried at the above temperature, whether used with or without pumice, chiefly on the ground that sulphur dioxide is formed, and he asserts that the formation takes place even when the copper sulphate is dried at a lower temperature than 150°. He also objects to the application of the method to coal gas, on the ground of action on the hydrocarbons of the gas of the sulphuric acid liberated from the copper sulphate as the latter is converted to sulphide. These aspersions on the method suggested by Fresenius appear sufficiently forcible to justify the adoption of the modification finally suggested by Lewis T. Wright in its stead. This consisted essentially in the use of an active cupric phosphate in place of the sulphate. The phosphate, which appears to vary somewhat in composition, is prepared by mixing 2 lbs. of common sodium phosphate (Na_2HPO_4) dissolved in a gallon of water, with 2½ lbs. of crystals of copper sulphate dissolved in 1½ gallons of water, and stirring vigorously. The resulting bright blue precipitate is washed by decantation, and dried at 100° C. Some of the material produced will be powdery, some in lumps, which may be broken to a convenient size. Care should be taken that the lumps are well surrounded by the powdery material in the filled tubes. The U-tubes used should, of course, have hollow glass stoppers ground in, the hollow of the stopper being filled with a loose plug of cotton wool. One limb of each tube is charged with the copper phosphate prepared as above directed, and the other limb is filled with non-alkaline calcium chloride. Dried clean coal gas is then passed through the tube at the rate of about a foot an hour for three or four hours, as copper phosphate gains in weight up to a certain limit under the action of coal gas. The tube, with its contents thus "saturated" with coal gas, is weighed, and is ready for use. The usual precautions of carefully greasing the stoppers, removing dust and extruding grease by carefully wiping the tubes with a dry cloth, and storing the tube in the dry atmosphere of the balance-case for half an hour before weighing must, of course, have been observed. The sample of gas to be examined must be passed through two bubbling tubes or Liebig bulbs containing dilute sulphuric acid for the retention of any ammonia present in the gas. It then passes through a large drying chamber packed closely with small lumps of calcium chloride free from alkaline reaction. The limb of the weighed U-tube containing the copper phosphate is connected to the outlet of the drying cylinder, and a small guard U-tube containing calcium chloride is attached to the other limb; the outlet of the guard tube leads to an aspirator of 3 or 4 gallons capacity. The stoppers of the U-tubes being turned to admit of the passage of gas, the tap of the aspirator is turned on, and the gas drawn through the train of apparatus. When the desired amount of gas has passed, the current is stopped, the water that has run from the aspirator is measured, and a quantity of clean (*i.e.*, free from sulphuretted hydrogen) gas is drawn through the whole of the train of apparatus to ensure the whole of the gas under examination passing from the drying chamber to the weighed tube. This tube is detached from the train after turning the stoppers, then carefully wiped, and left for half an hour in the balance-case before weighing. The difference between the first and second weights of the U-tube gives the amount of sulphuretted hydrogen absorbed, and the quantity of water passed from the aspirator gives the volume of gas (free from sulphuretted hydrogen) with which it was associated. The temperature of the gas in the aspirator should be observed at the time it is shut off on a thermometer passing through the plug in the top of the vessel, and the volume corrected to normal—say, 60° F., or 15·5° C. To this volume must be added the volume of the sulphuretted hydrogen absorbed by the U-tube. This may be found from the weight, since 1 grain of sulphuretted hydrogen has a volume of 45·00 c.c. or 0·001589 cubic foot at 15·5° C. and 760 mm. From the total volume so found of gas at 15·5° C. and 760 mm. entering the U-tube, the number of grains of sulphuretted hydrogen per 100 cubic feet, or the percentage by volume, can be readily calculated. The course of the absorption can be easily followed in the U-tube, as, if this is properly charged, there is a quite sharp line of demarcation between the sulphide and phosphate in it. When crude, or nearly crude, gas is under examination, 2 or 3 gallons of water run from the aspirator is amply sufficient for a reliable estimation; when the gas contains 200 grains or less of sulphuretted hydrogen per 100 cubic feet, it is desirable to substitute a small test meter for the aspirator, and to rely on the pressure to force the gas through the apparatus. From 1 cubic foot upwards may then be passed, and it becomes unnecessary to make an addition to the volume read off on the meter for the sulphuretted hydrogen absorbed. This method of estimating sulphuretted hydrogen in coal gas is the most exact known to the author, and with a little practice it will be found to constantly furnish reliable results. The greater part of the instructions for carrying out this test are taken from Lewis T. Wright's paper quoted above, but embody also the fruits of the author's experience with the test. Needless to say, with slight modification the apparatus may become part of a more extensive train, in which carbonic acid and ammonia are estimated at the same time as the sulphuretted hydrogen. This will be again alluded to when the estimation of carbonic acid is considered.

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* *Journ. Chem. Soc.*, vol. xliii., p. 267.

† Fresenius, *Quantitative Analysis*, 7th edition, p. 383.

There are many other methods of estimating sulphuretted hydrogen in gas by passing a known volume of the latter through some agent for absorbing the sulphuretted hydrogen. One method consists in bubbling the gas through tubes containing solution of cadmium chloride slightly acidified with hydrochloric acid. Cadmium sulphide is thrown down, but at least three bubbling tubes are generally necessary to ensure the whole of the sulphuretted hydrogen being retained. When the requisite volume of gas has passed, the precipitate may be washed on to a weighed filter, dried, and weighed; but it will be found easier and quite as accurate to wash the bulk of the sulphide on to a filter, and then to oxidize it and any precipitate remaining in the tubes with bromine water, subsequently boiling off the bromine and filtering, and estimating the sulphate in the filtrate and washings in the usual way as barium sulphate. The weight of barium sulphate found multiplied by 0·146 gives the weight of sulphuretted hydrogen absorbed, and the calculation to grains per 100 cubic feet or per cent. by volume may be made as before. This method is rather tedious, but may be used when cupric phosphate tubes are unprepared, and a test is wanted immediately on a particular stream of gas.

Sulphuretted hydrogen in coal gas may be estimated by several other methods, but they do not present any great advantage over those given. One method very commonly given in text-books, with slight variations of detail only, is the absorption of the sulphuretted hydrogen by bubbling the gas through solution of lead acetate or nitrate; the lead sulphide is filtered off, and oxidized with fuming nitric acid to lead sulphate, which is ignited and weighed. When the gas for testing contains tar and ammonia, they must be removed by passing it through a scrubbing apparatus of broken glass or pumice wetted with dilute acid before it enters the vessel containing the lead salt solution. Some of the lead salt may be carried down with the lead sulphide, but this can be removed by washing after oxidizing with nitric acid. An aspirator or meter may be used for measuring the volume of the gas according to the conditions of testing.

The method of estimating sulphuretted hydrogen in a small sample of gas in the ordinary analysis apparatus has already been given on p. 174.

Estimation of Carbon Dioxide.—Carbon dioxide or carbonic acid in illuminating gas may be estimated in several ways with accuracy. Its presence is ascertained by bubbling some of the gas from a capillary orifice through a clear solution of calcium hydrate (lime water) or through solution of barium hydrate. If carbonic acid is present to an appreciable extent, a white precipitate of calcium or barium carbonate forms, and gives a milky appearance to the previously clear solution. Lime water is ordinarily used for testing the gas for carbonic acid at small outlet pipes fixed above each tier in the lime purifiers, for the purpose of indicating the course of the purification. Lime water is prepared by agitating tolerably pure slaked lime with water, and allowing excess of lime and any carbonate formed to subside. The clear supernatant liquid may be siphoned off as required for use, contact with air being avoided as much as possible throughout.

Solution of barium hydrate may be used for the quantitative determination also of carbonic acid in gas. The process is based on Pettenkofer's method for the determination of carbonic acid in air. A nearly saturated solution of barium hydrate is prepared by putting 2 to 3 lbs. of crystals of the hydrate in a 2- or 3-gallon glass jar, and filling it with distilled water recently boiled, and covering so as to exclude air from the jar. In a few days' time the bulk of the clear liquid is drawn off into a rather smaller glass bottle, the mouth of which is provided with a well-fitting caoutchouc plug having two perforations. Through one of these passes the shorter limb of a glass siphon tube, the end of the longer external limb being fitted with a piece of flexible tubing with spring clip and glass mouthpiece, through which the solution is drawn off as required. Through the second perforation passes the contracted end of a tube packed (above a short plug of cotton-wool) with soda-lime, and having its upper end connected to a piece of flexible tubing furnished with a spring clip. As the solution is drawn from the bottle, air is admitted by opening this spring clip, and is deprived of carbonic acid by the soda-lime, so that the strength of the solution remains unaffected.

For titrating the solution to ascertain its strength, a decinormal solution of hydrochloric or oxalic acid may conveniently be used. The method of preparing either of these solutions is given in the ordinary text-books on volumetric analysis.* 1 c.c. of decinormal acid is equivalent to 0·0022 gram of carbon dioxide. 25 or 50 c.c. of the solution of barium hydrate is run from an accurately marked pipette into a small flask, and a few drops of alcoholic solution of phenolphthalein are added. Decinormal acid is run into the flask until the pink colouration is discharged. The exact point of neutralization may be ascertained in a second or third titration, the acid being run in rapidly until the point is nearly reached. By this plan prolonged contact of the barium-hydrate solution with the air during titration is avoided. Suppose 25 c.c. of the barium-hydrate solution require 16·0 c.c. of $\frac{N}{10}$ (decinormal) acid for neutralization, then that volume of solution will absorb exactly (16 × 0·0022) gram of carbon dioxide, and 100 c.c. of the barium-hydrate solution will absorb (4 × 16 × 0·0022) = (64 × 0·0022) = 0·1408 gram of carbon

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[*] Sutton, *Volumetric Analysis*, sixth edition, pp. 42 and 43.

dioxide. If a known volume of gas is passed through a known volume of standardized solution of barium hydrate, and the loss of alkalinity of the solution ascertained afterwards by titration, we have the data for finding the amount of carbonic acid in the gas. The author carries out the determination on crude or nearly crude coal or water gas, somewhat after the following manner:—Let the period of testing be prolonged over some hours, and the volume of gas passed be tolerably large. The gas should be drawn from a service in which a good circulation is maintained by continuously burning the gas at a jet a few inches above the cock from which the supply is taken for testing. A two-necked Wolff's bottle, with well-fitting caoutchouc plugs perforated for glass tubes, has poured into it from a measuring flask, with as little agitation as possible, 500 c.c. of the standardized solution of barium hydrate. The tube passing through one plug dips beneath the solution to within half an inch of the bottom of the bottle, and is contracted at its mouth to about $\frac{1}{12}$ of an inch. The glass tube through the other plug ends just below the plug. The bottle is of such size that the solution fills about two-thirds of it. A smaller similar bottle, or straight glass jar, fitted with a plug bored for the two tubes, is charged with 100 c.c. of the solution of barium hydrate. The tube that dips down beneath the liquid in this vessel has a capillary orifice. The gas should pass through a small purifier charged with oxide of iron before it reaches the junction of the supply cock with the service pipe; if the purifier is put between the junction and the testing apparatus, the test will be made chiefly on the stagnant gas left in the purifier after blowing it, and will not be representative of the gas passing up the service pipe during the time the test is running. To the supply cock the long tube of the large Wolff's bottle is connected with a short length of flexible tubing, the outlet tube of this bottle is similarly connected to the long tube of the smaller bottle, the outlet tube of which leads to the top of an aspirating bottle of about 3 gallons capacity. This aspirating bottle may conveniently have a large thistle-funnel with stop-cock passing through its plug for convenience in refilling, when the test is often repeated in the same spot. The aspirator has been filled with water prior to connecting up with the bottles, and is furnished with an easily regulated outlet tap. The supply-cock is turned on, and then the tap of the aspirator, to an extent sufficient to allow a steady stream of bubbles to pass through the solutions. The water having run out for the time desired for the test, the gas-cock is shut, and the tap of the aspirator as soon as the pressure within the aspirating bottle has been reduced to atmospheric. If the test has been running for some few hours, the temperature of the gas in the bottle may be taken at that of the atmosphere near by. For a rapid test, the thermometer should pass through the plug of the aspirator into the gas itself. The quantity of water that has passed from the aspirator should be measured in cubic centimetres. The flexible tube should be disconnected from the gas-cock, and connected to a washing bottle containing solution of caustic potash, and about a litre of air drawn through the apparatus. The Wolff's bottles are then disconnected, and the contents *rapidly* washed into a litre flask, with distilled water recently boiled and cooled, without free access of air. A supply of this boiled water may conveniently be kept in a bottle fitted up in the same way as that which contains the barium-hydrate solution. The flask, after being well shaken, to thoroughly mix the solution and washings, is allowed to stand for an hour. 100 c.c. is then drawn from the clear liquid without disturbing the precipitate which has settled to the bottom of the flask, and is titrated in a flask with decinormal acid, using phenolphthalein as an indicator as before. A second titration may be made, if necessary, on another 100 c.c. of the clear liquid.

We now have the data for calculating the results. Let the volume passed, as shown by the water run from the aspirator, be, in a given case, 5,630 c.c. at 15·5° C. and 760 mm. Let 25 c.c. of the standard solution of barium hydrate be neutralized by 16·0 c.c. of $\frac{N}{10}$ acid. Then, since 500 + 100 c.c. of the standard solution was used, the whole volume would be neutralized by $\frac{600}{25} \times 16{\cdot}0$ c.c. $\frac{N}{10}$ acid $= 384{\cdot}0$ c.c. $\frac{N}{10}$ acid. Let the 100 c.c. taken from the solution after use, and making up to a litre, require 18·0 c.c. of $\frac{N}{10}$ acid for neutralization. Then the whole of the solution after use requires $\frac{1{,}000}{100} \times 18{\cdot}0$ c.c. $= 180{\cdot}0$ c.c. $\frac{N}{10}$ acid for neutralization. The barium hydrate neutralized by the carbonic acid in the gas would be neutralized by $(384{\cdot}0 - 180{\cdot}0)$ c.c. $\frac{N}{10}$ acid $= 204$ c.c. $\frac{N}{10}$ acid, and, therefore, $(204 \times 0{\cdot}0022) = 0{\cdot}4488$ gram of carbon dioxide was in the gas. Now, 1 gram of carbon dioxide has a volume of nearly 538 c.c. at 15·5° and 760 mm. Therefore, the volume of carbon dioxide absorbed from the gas is $(0{\cdot}4488 \times 538) = 241{\cdot}45$ c.c. The volume of gas on which the test was made is $5{,}630 + 241{\cdot}45 = 5{,}871{\cdot}45$ c.c. at

15·5° C. and 760 mm. (The volume of carbonic acid absorbed must necessarily be added to the volume measured by the aspirator to get the true total volume of the gas for the calculation.) Hence, 5,871·45 c.c. of gas contain 241·45 c.c. of carbonic acid, or 100 c.c. contain 4·11 c.c., or the gas contains 4·11 per cent. by volume of carbonic acid. Such a quantity will sometimes be found in water gas, but points to bad working of the plant.

The result is in practice attained very easily. The factor for converting cubic centimetres of $\frac{N}{10}$ acid into cubic centimetres of carbon dioxide at 15·5° C. and 760 mm. is 1·184 nearly. The amount of $\frac{N}{10}$ acid which would neutralize the whole of the barium hydroxide solution taken for the test is known both for before and for after the passage of the gas from the titrations; the difference between these amounts (in cubic centimetres) multiplied by 1·184 gives the number of cubic centimetres of carbon dioxide in the volume of gas passed into the apparatus. This is added to the number of cubic centimetres of water run from the aspirator, and from this total volume and the volume of carbon dioxide, the percentage is at once found. With even moderate care, the results are accurate to within 0·1 per cent. A single test may be of any duration from fifteen minutes to twenty-four hours, the quantity of solution taken and the rate of passage of the gas being regulated accordingly. The gas should enter the apparatus at a tolerably constant pressure, hence in many cases it will be advisable to have a governor on the service used. From ½ to 1 inch of water pressure is a convenient one to work with. The author has used this test daily for some time to control the working of a water-gas plant, each test running for about twenty-three hours per day, and so giving a correct average for the day. The results may be converted into grains per 100 cubic feet without difficulty, even supposing the metrical system has been used, as in the above example. The total volume of gas (in cubic centimetres) found as above divided by 28,315·3 gives the volume in cubic feet (generally, of course, less than 1 cubic foot). Then the number of grams of carbon dioxide found as above multiplied by 15·43235 gives the number of grains of carbon dioxide in the volume of gas passed. From this the grains per 100 cubic feet are directly found. For instance, in the above example,

$$5871{\cdot}5 \div 28315{\cdot}3 = 0{\cdot}20736 \text{ cubic foot.}$$

$$0{\cdot}4488 \times 15{\cdot}43235 = 6{\cdot}926 \text{ grains.}$$

$$\therefore \quad \frac{6{\cdot}926 \times 100}{0{\cdot}20736} = 3{,}340.$$

Or, the gas contains 3,340 grains of carbonic acid per 100 cubic feet. An illustration of the apparatus and connections is given in Fig. 37, where A is the oxide purifier on the supply pipe; B, the jet at which the gas is kept burning; C and D, the bottles containing the barium hydrate solution; E, the aspirator, with funnel for refilling, F, and thermometer, G. The water from the aspirator runs into the can, H, and is afterwards measured.

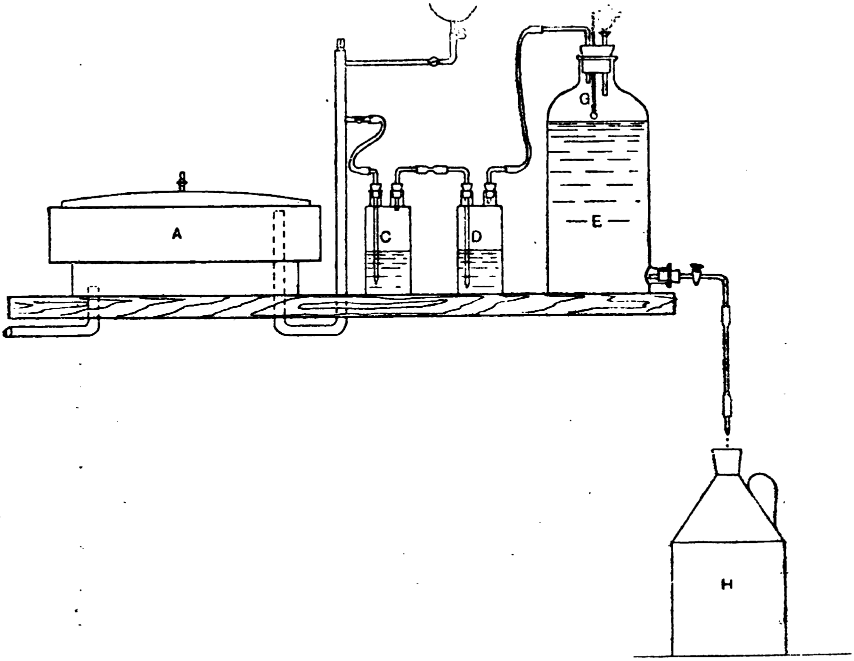

Fig. 37.—Apparatus for determining carbon dioxide in gas.

A, Oxide purifier; B, gas jet; C, D, bottles with barium hydrate solution; E, aspirator; F, funnel; G, thermometer; H, can.

Carbonic acid in gas may be readily estimated by absorption in weighed tubes containing soda-lime, or in weighed Liebig bulbs filled with solution of caustic potash. Tar, ammonia, and sulphuretted hydrogen, if present, must be first removed from the gas—the first two by bubbling through weak acid, the last by a small oxide purifier. The gas must then be dried by passing through a large cylinder of calcium chloride, followed by a small catch U-tube containing the same material. This tube should remain of constant weight. The calcium chloride must not be alkaline. Then follow two U-tubes, each containing soda-lime in the first limb and calcium chloride in the second. These tubes are weighed (the air within having been displaced by clean coal gas) separately before the experiment and also afterwards, with the usual precautions. The sum of their increases in weight is the weight of the carbonic acid absorbed from the volume of gas passed through them. These tubes are followed by a catch U-tube containing calcium chloride; the outlet of this tube is connected to the aspirator or small meter. This estimation of carbonic acid may be combined with that for sulphuretted hydrogen described on p. 192, by placing the drying cylinder next to the acid for ammonia absorption, then the copper phosphate tube, followed by the soda-lime tubes.* When the desired volume of gas has passed through the tubes, the aspirator tap is closed, and the volume ascertained in the usual way, or the meter read. Then a wash-bottle containing solution of caustic potash is placed before the calcium chloride drying cylinder, and about half a cubic foot of gas (freed from carbonic acid by the potash solution) is passed through the train of apparatus, to ensure absorption of the carbonic acid from the gas remaining in the vessels. The estimation is quite reliable if sufficient care is taken to perfectly dry the gas before it enters the weighed tubes. Liebig bulbs charged with solution of potash, and followed by a small U-tube containing calcium chloride, may replace the soda-lime tubes, and are easier of preparation. The bulbs, with inlet and outlet tubes plugged, are weighed together with the calcium chloride tube; the increase in weight during the experiment gives the amount of carbonic acid absorbed.

Carbonic acid in coal gas may be approximately estimated by a modification of Harcourt's colour test for the estimation of sulphuretted hydrogen. A standard tube containing a known amount of barium carbonate in the liquid is prepared, and gas bubbled through the same volume of solution of barium hydrate in a similar tube, until the opacity of the two liquids appears equal against a black background. The amount of carbonic acid required to produce this degree of opacity being known, the percentage is calculated from the volume of gas passed. Tables have been prepared to facilitate the calculation, but the method does not appear to have been extensively used; and it certainly needs a considerable amount of practice to obtain accurate results.

Carbonic acid in a small collected sample of gas, or in spent furnace gas, may be estimated by methods already described with the various forms of gas analysis apparatus.

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* Lewis T. Wright, *Journ. Chem. Soc.*, vol. xliii., p. 274.

Estimation of Sulphur Compounds.—Carbon disulphide and other sulphur compounds in gas may be estimated by two or three well-known methods. The most general method of estimating the sulphur present in gas freed from sulphuretted hydrogen is that prescribed by the Metropolitan Gas Referees for the testing of London gas. It is the outcome of experience with several earlier processes, of which it is a modification, and with slight variations of detail, is largely used on the Continent and elsewhere. The instructions issued by the Gas Referees read as follows :—

"**Sulphur Compounds other than Sulphuretted Hydrogen.**—The gas which has been tested for sulphuretted hydrogen and ammonia shall pass next through a meter, by means of which the rate of flow can be adjusted to half a cubic foot per hour, and which is provided with a self-acting movement for shutting off the gas when 10 cubic feet have passed. The testing shall be made in a room where no gas is burnt other than that which is being tested for sulphur and ammonia. The apparatus to be employed is represented by the diagram (Fig. 38), and is of the following description :—The gas is burned in a small Bunsen burner with steatite top, which is mounted on a short cylindrical stand, perforated with holes for the admission of air, and having on its upper surface a deep circular channel to receive the wide end of a glass trumpet-tube. On the top of the stand, between the narrow stem of the burner and the surrounding glass trumpet-tube, are to be placed pieces of commercial sesquicarbonate of ammonia, weighing in all about 2 ounces."

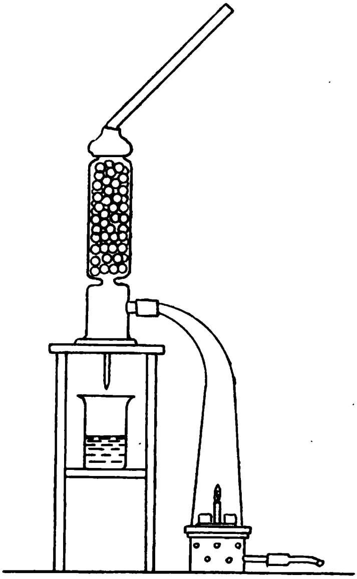

Fig. 38.—The Referees' apparatus for the determination of sulphur in gas.

"The products, both of the combustion of the gas and of the gradual volatilization of the ammonia salt, go upwards through the trumpet-tube into a vertical glass cylinder, packed with balls of glass, to break up the current and promote condensation. From the top of the cylinder there proceeds a long glass pipe or chimney, serving to effect some further condensation, as well as to regulate the draught and afford an exit for the uncondensable gases. In the bottom of the cylinder is fixed a small glass tube, through which the liquid (formed during the testing) drops into a beaker placed beneath.

"The following cautions are to be observed in selecting and setting up the apparatus:—

"See that the inlet-pipe fits gas-tight into the burner, and that the holes in the circular stand are clear. If the burner gives a luminous flame remove the top piece, and having hammered down gently the nozzle of soft metal perforate it afresh, making as small a hole as will give passage to half a cubic foot of gas per hour at a convenient pressure.

"See that the tubulure of the condenser has an internal diameter of not less than $\frac{3}{4}$ inch, and that its outside is smooth and of the same size as the small end of the trumpet-tube.

"See that the short piece of indiarubber pipe fits tightly, both to the trumpet-tube and to the tubulure of the condenser.

"The small tube at the bottom of the condenser should have its lower end contracted, so that when in use it may be closed by a drop of water.

"The indiarubber pipe at the lower end of the chimney-tube should fit into or over, and not simply rest upon, the mouth of the condenser, and the upper extremity of this tube may with advantage be given a downward curvature.

"At the end of each period of testing, the cylinder and trumpet-tube are to be well washed out with distilled water. Fresh pieces of sesquicarbonate of ammonia are to be used each day.

"The gas examiner shall then proceed as follows:—

"The liquid in the beaker, and the water used in washing out the apparatus, shall be put into the same vessel, well mixed, and measured. One-half of the liquid so obtained is to be set aside and preserved for a week, properly labelled, in case it should be desirable to verify the correctness of the testing.

"The remaining half of the liquid is to be put into a flask, or beaker covered with a large watch-glass, treated with hydrochloric acid sufficient in quantity to leave an excess of acid in the solution, and then raised to the boiling-point. An excess of a solution of barium chloride is now to be added, and the boiling continued for five minutes. The vessel and its contents are to be allowed to stand till the barium sulphate settles at the bottom of the vessel, after which the clear liquid is to be as far as possible poured off through a paper filter. The remaining liquid and barium sulphate are then to be poured on to the filter, and the latter well washed with hot distilled water. (In order to ascertain whether every trace of barium chloride and ammonium chloride has been removed, a small quantity of the washings from the filter should be placed in a test-tube, and a drop of a solution of silver nitrate added; should the liquid instead of remaining perfectly clear, become cloudy, the washing must be continued until, on repeating the test, no cloudiness is produced.) Dry the filter with its contents, and transfer it into a weighed platinum crucible. Heat the crucible over a lamp, increasing the temperature gradually, from the point at which the paper begins to char up to bright redness.* When no black particles remain allow the crucible to cool; place it when nearly cold in a desiccator over strong sulphuric acid, and again weigh it. The difference between the first and second weighings of the crucible will give the number of grains of barium sulphate. Multiply this number by 11 and divide by 4; the result is the number of grains of sulphur in 100 cubic feet of the gas. This number is to be corrected for the variation of temperature and atmospheric pressure, in the manner indicated under the head of illuminating power (see p. 230), with this difference, that the readings of the barometer and thermometer, or of the aërorthometer, are to be taken for the day on which the testing commenced, and also the day on which it closed; and the mean of the two is to be used. The reading of the aërorthometer at the time at which the passage of gas through the meter is cut off may be taken by means of a registering aërorthometer, in which the column of mercury is shut off by a lever-tap similar to, and connected with, that of the meter. The correction by means of the tabular number may be made most simply, and with sufficient accuracy, in the following manner:—

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* An equally good and more expeditious method is to drop the filter with its contents, drained but not dried, into the red-hot crucible.

"When the tabular number is between 955-965, 966-975, 976-985, 986-995, increase the number of grains of sulphur by $\frac{4}{100}$, $\frac{3}{100}$, $\frac{2}{100}$, $\frac{1}{100}$. When the tabular number is between 996-1,005 no correction need be made. When the tabular number is between 1,006-1,015, 1,016-1,025, 1,026-1,035, diminish the number of grains of sulphur by $\frac{1}{100}$, $\frac{2}{100}$, $\frac{3}{100}$.

"Example—

"Grains of barium sulphate from 5 cubic feet of gas, . .	4·3
"Multiply by 11, and divide by 4, ...	11
	4)47·3
"Grains of sulphur in 100 cubic feet of gas (uncorrected) = .	11·82
"Add 11·8 × $\frac{2}{100}$ = .	0·24
"Grains of sulphur in 100 cubic feet of gas (corrected) = .	12·06

Barometer (mean), 29·4

Thermometer (mean), 58

Tabular number, . 985

"Result, . . 12·1 grains."

It will be observed that the instructions are so worded, and so explicit, that they may be carried out by one unacquainted with the ordinary routine of laboratory work. At the official testing stations they must in no way be departed from, and it is desirable for every works manager to see that a test is put on the outlet main from the works in strict accordance with these instructions. The maximum amount of sulphur (from sulphur compounds other than sulphuretted hydrogen) with which gas shall be allowed to be charged (in the Metropolis) shall be 22 grains in winter, and 17 grains in summer, of sulphur in every 100 cubic feet of gas. For tests about a works for controlling the purification, &c., some modifications of the Referees' method of testing become permissible, and even desirable. Provided the gas is burnt at the rate of half a cubic foot per hour, it is not essential for the test to be on 10 cubic feet of gas. The test may be stopped at any time and the liquor and washings worked up, provided the number of feet of gas burnt is read, and the result corrected accordingly. Thus, if the calculation is performed in the manner described above, the result found must be multiplied by 10 and divided by the actual number of feet burnt to give the correct result. If less than 5 feet of gas has been burnt in the test, it is advisable to use the whole of the liquor and washings for the precipitation, &c. In such cases, it is simpler to make the calculation of the result according to the ordinary figures, and to avoid the mystic $\frac{11}{4}$ of the Referees' instructions. For example, suppose 3·5 cubic feet of gas has been burnt, and the precipitate of barium sulphate from the whole of the liquor and washings weighs 3·15 grains. Since 233 parts of barium sulphate contain 32 parts of sulphur, this weight of precipitate is equivalent to $\frac{3{\cdot}15 \times 32}{233}$ grains of sulphur, which is contained in 3·5 cubic feet of gas. Therefore, 100 cubic feet of gas would contain—

$$\frac{3{\cdot}15 \times 32 \times 100}{233 \times 3{\cdot}5} = 12{\cdot}34 \text{ grains of sulphur.}$$

The liquid in the beaker and washings are usually made up to 1 decigallon in a measuring flask; when well mixed this is halved by pouring out a half decigallon into a measuring flask of that capacity. Whichever half is used, the flask which contained it must be well washed out with distilled water, the washings going into the beaker containing the liquid from the flask. Where a large number of tests have to be made daily, time in filtering and washing is saved if only a quarter of the liquid is taken for precipitating. If the whole is made up to a decigallon, a fourth is conveniently taken out for the testing by means of a 250-septem pipette. If a quarter of, instead of half, the liquid is taken, the result must be calculated accordingly. It would savour of gnat-straining pedantry to make correction for temperature and pressure in tests merely used for the purpose of regulating the working of the purifiers, unless the atmospheric conditions are extremely abnormal. It is not advisable to keep a sulphur test burning more than the prescribed 20 hours, as the carbonate of ammonia becomes considerably exhausted in that time. The test should be carried out in a room of which the temperature does not fall much below 60° F.

Suggestions have been made from time to time for improving the Referees' method, since it is possible to obtain slightly higher figures by adopting means to ensure the complete oxidation of all the sulphur in the gas, as a small amount may, with the ordinary method, be consumed to sulphur dioxide only. Wanklyn has proposed to put iodine at the top of the condenser, in place of ammonium carbonate round the burner, but there is some risk of the formation of iodine compounds of nitrogen which explode violently. A better suggestion is that of T. Fairley,* who proposes to run in slowly at the top of the condenser, a 1 per cent. solution of hydrogen dioxide, and to omit the ammonium carbonate round the burner. The solution should drop in at the rate of about 3 c.c. per hour. If the hydrogen dioxide is freed from any barium or sulphuric acid present in it before use, the condensed liquid and washings may be used for the estimation of the sulphur as barium sulphate in the usual way. Suggestions have been made with a view to rendering the estimation more rapid of execution. Thus Fairley proposes to estimate the sulphuric acid in the condensed liquid (hydrogen dioxide having been used during the combustion to oxidize any sulphur dioxide) by titrating with standard solution of soda or potash. Sadler and Silliman drop in standard solution of carbonate of soda or potash at the top of the cylinder, and estimate the sulphur by the loss of alkalinity, as shown by subsequent titration. Of course ammonium carbonate is not used round the burner, and the gas must be free from ammonia, as indeed it should be for Fairley's method. The results obtained by most of these modifications of the Referees' method are higher by about 0·5 to 2·0 grains of sulphur than those obtained by their method. The author's experience leads him to believe more consistent results are obtained if the liquor from an ordinary Referees' testing apparatus is acidified with nitric in place of hydrochloric acid, and barium nitrate used in place of barium chloride as the precipitating agent. The procedure is exactly similar in other respects to that of the official method, but especial care must be taken that the washing is thorough, as no such simple check as the silver-nitrate test for chloride can be applied to the washings. In some cases the results are similar by the use of nitrate or chloride, but in most cases the nitrate gives a slightly higher result, suggesting that when combustion has been rather imperfect, the nitric acid effects the oxidation of any sulphite in the liquid. The small fluctuations which are often found with the Referees' tests are largely avoided by using nitric acid and barium nitrate in the estimation.

It is improbable that sulphur in coal gas, in whatever combination it is present, escapes estimation by careful combustion by the Referees' plan. The process is, however, slow and somewhat exacting, and rather fitted for ascertaining the average amount of sulphur present in the gas supply for the whole day, than for a rapid estimation on a works for the purpose of learning the effectiveness of the purification carried out by a set of purifiers at any particular time. Where a sulphide vessel is, or is suspected of, working badly, it is very necessary to be able to learn in a short time the amount of sulphur compounds in the gas leaving it. The want is fully met by the test devised by A. Vernon Harcourt, one of the Gas Referees of the Metropolis; for although the sulphur present as carbon disulphide alone appears to be estimated by it, the other sulphur compounds of coal gas occur always in nearly constant quantity, and the total amount of sulphur present in the gas may be found by adding a certain constant to the amount indicated by this test, the general usefulness of which is in no way impaired. The gas to be tested is passed over heated platinized pumice or asbestos, which breaks up any carbon disulphide present with production of the equivalent amount of sulphuretted hydrogen. The gas carries forward the latter into a solution of acetate of lead, in which the precipitate of lead sulphide is allowed to form until the colouration is equal to that of a standard solution. The gas is measured after passing through the lead solution, and from the volume of gas which has passed before the desired tint is attained in the solution, the amount of sulphur impurity present is calculated. The test in practice is carried out somewhat in the following manner :—

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* *Journ. Soc. Chem. Ind.*, 1886, p. 283; and *ibid.*, 1892, p. 419.

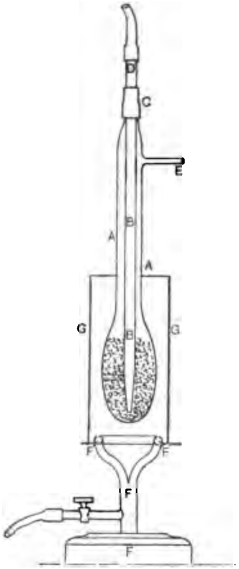

Fig. 39.—Bulbed tube and burner of Harcourt's apparatus for determining sulphur in gas.

A, Bulbed tube with pumice; B, glass tube; C, joint; D, end of glass tube B; E, arm of tube A; F, Argand burner; G, chimney.

The bulb of the bulbed glass tube, A (Fig. 39), is filled with lumps, about the size of small peas, of well platinized pumice, the glass tube, B, is inserted with its capillary orifice within a quarter of an inch of the bulb wall, and a close joint made at C, with stout caoutchouc tubing. The protruding end, D, of B is connected to the gas supply. The arm, E, of A conveys away the gas, which has passed down B and up through the asbestos in the bulb to the lead solution. This is contained in a tube of the same diameter and of similar glass to that containing the colour standard, and reaches up to a line scratched on the tube. The tube is furnished with a caoutchouc plug, through which two tubes pass, one ending with a capillary orifice close to the bottom of the tube, and serving to lead the gas in, the other passing little more than through the plug, and serving as the exit tube. The former, or inlet tube, is connected to E (Fig. 39), the latter to the top of an aspirating bottle. The water from the aspirator is, when a test is being made, run into a graduated measure, and the volume of gas passed through the tubes ascertained by a direct reading of the water in the measure. The measure ordinarily used has a capacity of $\frac{1}{20}$ of a cubic foot, and is marked in 100 equal divisions, each of which, therefore, represents $\frac{1}{2000}$ of a cubic foot. The plugs in the aspirator and bubbling tube must, of course, fit perfectly air-tight. To make a test, the gas supply is connected up to D, and allowed to pass through the bulb, and out by E, at the rate of about half a foot an hour. The small Argand burner, F, below the bulb is lighted, and turned down so as to give merely a blue ring of flame. The chimney, G, is of either porcelain or glass. When the gas has been passing through the heated bulb for about ten minutes, the outlet, E, is ready to be connected to the bubbling tube. The solution of lead acetate used is prepared by diluting a specially supplied lead syrup to twenty times its volume with distilled water. The bubbling tube is filled up to the mark on it with the solution so formed, the plug inserted in it, and the outlet tube connected to the aspirator. One of the specially supplied tubes, filled with an artificially prepared liquid of the exact tint which sulphuretted hydrogen, containing 0·0025 grain of sulphur would give to the quantity of lead solution used in one of the tubes supplied, is taken and placed alongside the bubbling tube on a clean white surface against a clean white background. The inlet tube, with its capillary orifice well immersed in the lead solution, is connected to the arm, E, of the bulbed tube, and the tap of the aspirator turned so as to allow a stream of bubbles to pass slowly through the lead solution. The water from the aspirator is collected in the graduated measure, which must be emptied before each test. The colour of the lead solution is carefully watched, and as soon as it approaches that of the standard liquid, the stream is checked, and the tap of the aspirator turned off at intervals to enable an exact comparison of the colours of the liquids in the two glasses to be made. When they appear to be of exactly the same tint, the aspirator tap is finally shut, and the volume of water run from it read on the graduated measure. The divisions on the measure each represent, as already stated, a 2,000th part of a cubic foot, hence we have the volume of gas passed stated as so many 2,000ths of a cubic foot. The colouration of the volume of lead solution in the prescribed bubbling tube to the standard tint is effected by sulphuretted hydrogen equivalent to 0·0025 grain of sulphur. If the water fill x divisions on the measuring cylinder, then 0·0025 grain of sulphur is contained in $\frac{x}{2,000}$ of a cubic foot, and x cubic feet of the gas contain 5 grains of sulphur. Therefore, 100 cubic feet will contain $\frac{500}{x}$ grains of sulphur. The number so found represents only the sulphur compounds (almost solely carbon disulphide) in the gas which are converted to sulphuretted hydrogen on passing over heated platinized pumice. The other sulphur compounds in ordinary coal gas amount almost constantly to about 8 grains (of sulphur) per 100 cubic feet, and this number (8) is usually added to the number found from the above formula, to give the total number of grains of sulphur present in 100 cubic feet of the gas. Therefore we have, where x represents the number of divisions of the measure filled with water from the aspirator—

Grains of sulphur in total sulphur compounds in 100 cubic feet of gas

$$= \frac{500}{x} + 8.$$

Of course, if the gas contains sulphuretted hydrogen, this would be included in the figure obtained. Therefore, when the test is applied to crude or partially purified gas, a cylindrical glass vessel packed with iron oxide should be placed between the gas supply cock and the inlet to the bulbed tube. The oxide will take up the sulphuretted hydrogen from the gas, and only the "sulphur compounds" will be estimated. The appearance of the testing apparatus is shown in Fig. 40, where H is the oxide purifier, A the bulb tube containing platinized pumice, K the bubbling tube containing lead solution, M the tube containing the standard liquid, N the aspirator, and P the measuring cylinder. As the apparatus is often used in the open, it is advisable to have the bulbed tube and the Argand burner enclosed in a plate glass case, with metal framework and top to protect the flame from draughts. It is also desirable to have a small governor on the inlet tube, R, to reduce the pressure, if the apparatus is to be used on gas at high pressure. There are two standards supplied, one for use by artificial light, the other for use by daylight. The tubes have the top sealed, and the contained coloured liquid remains unchanged for a long period. The apparatus, lead syrup, standard glasses, and other accessories are supplied by S. E. Miller, 115 Cowley Road, Oxford.

The Harcourt colour test can, as mentioned on p. 191, be readily applied to the estimation of sulphuretted hydrogen in gas. The gas supply is directly connected to the bubbling tube, and the test made in a similar manner to the above. The bulbed tube, burner, and purifier are, of course, unnecessary when estimating sulphuretted hydrogen only. It would be desirable in most instances to blow off gas from an arm of the tube near the inlet to the bubbling vessel, as thereby the use of

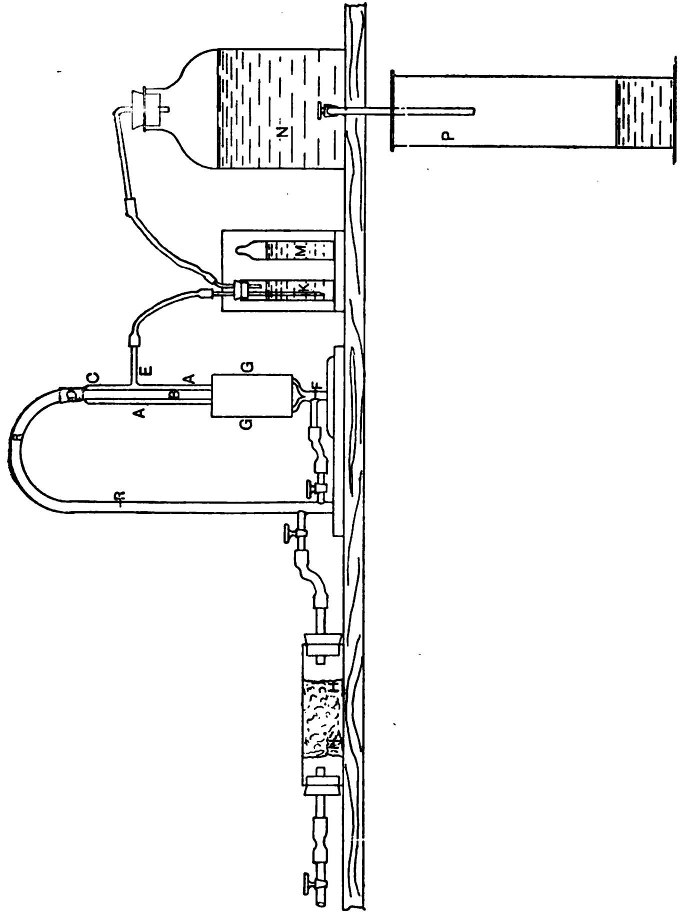

Fig. 40.—Harcourt's apparatus for the determination of sulphur in gas.

A, Bulb tube with pumice; H, oxide purifier; K, tube with lead solution; M, tube with standard liquid; N, aspirator; P, measuring cylinder; R, inlet pipe.

stale gas only for the test is avoided. For most tests for sulphuretted hydrogen on crude or nearly crude gas, a smaller measuring cylinder, containing $\frac{1}{200}$ of a cubic foot, and divided into 100 parts, must be substituted for the large one used when testing for sulphur compounds. Each division represents $\frac{1}{20000}$ of a cubic foot, and if the water from the aspirator in a test occupies x divisions, then $\frac{x}{20,000}$ cubic feet of gas contain sulphuretted hydrogen equivalent to 0·0025 grain of sulphur. Therefore, 100 cubic feet of the gas contain $\frac{5,000}{x}$ grains of sulphur as sulphuretted hydrogen. For gas containing less than 50 grains of sulphur per 100 cubic feet, the larger measuring cylinder should be used. 100 grains of sulphur represent 106¼ grains of sulphuretted hydrogen.

The decomposition of carbon disulphide and some other sulphur compounds by heated platinized pumice or asbestos, has been applied by O. Knublauch to their determination in coal gas.* The gas, mixed with five times its volume of air, is passed over the platinized asbestos in a glass tube heated externally, and then led into absorption tubes or bulbs filled with solution of potassium carbonate. At the close of the test the solution is oxidized with a little potassium permanganate, and the sulphate present precipitated as the barium salt, and weighed in the usual manner. The gas is passed over the asbestos at the rate of ¾ cubic foot per hour.

Carbon disulphide in gas may be estimated in the following manner:—The gas is passed through a long tube containing neutral calcium chloride, and then into a saturated solution of fused potash in absolute alcohol. The volume of gas passed is measured. Carbon disulphide combines with potassium ethylate (alcoholic potash) to form potassium xanthate, consisting of colourless needles, thus—

$$CS_2 + C_2H_5OK = CS(C_2H_5O)SK.$$

The solution is neutralized, when the desired quantity of gas has passed, with acetic acid, and diluted. The potassium xanthate is converted to copper xanthate—a yellow precipitate—by the addition of a copper salt. The potassium xanthate in the solution is estimated by titrating with normal solution of copper sulphate, the end of the reaction being found by bringing from time to time a drop of the solution in contact with a drop of solution of potassium ferrocyanide. As soon as the whole of the potassium xanthate is converted to copper xanthate, excess of copper appears in the solution, and is indicated by colouring the ferrocyanide solution. From the volume of normal copper sulphate required to decompose the potassium xanthate, the amount of carbon disulphide in the volume of gas passed through the alcoholic solution is readily calculated.

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* *Berichte d. d. Chem. Ges.*, vol. xv., p. 1882.

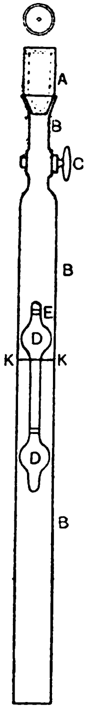

Fig. 41.—Apparatus for Bunsen's effusion test of the specific gravity of gas.

A, Glass tube with platinum foil; B, glass vessel; C, stop-cock; D, float; E, top of float.

Normal solution of copper sulphate contains 12·45 grams of the crystallized salt ($CuSO_4 + 5H_2O$) to the litre, and 1 c.c. of this solution represents 0·0076 gram (= 0·1173 grain) of carbon disulphide.

Triethylphosphine [$P(C_2H_5)_3$] is a most delicate test for carbon disulphide, forming with it brilliant red crystals, crystallizing well from ether. The test is seldom made use of, except to detect traces of carbon disulphide.

Estimation of Specific Gravity.—The specific gravity of gas is to a certain extent indicative of its quality, and more especially so when gases from similar sources, and presumably owing their illuminating power to the same hydrocarbons, only are compared. With illuminating gases of totally diverse constitution, the densities give no criterion of the relative lighting powers. A knowledge of the approximate specific gravity of a given kind of gas is necessary when determining the diameter of main required for its distribution. For this reason, rather than for the uncertain light thrown on its illuminating value, a method of ascertaining the specific gravity of gas is here described. The method most easily carried out, and withal the most accurate with apparatus of moderate cost, is an indirect one first used by Bunsen. It is based on the fact that gases issuing under similar conditions of pressure from a tiny hole in a metallic plate, flow through it at rates which vary inversely as the square roots of their densities. This fact, first demonstrated by Graham, is for most gases a very close approximation to the truth. Bunsen made use of it in his effusion test, in which he observes the time taken by a given volume of gas to pass through a small (about $\frac{1}{300}$ of an inch diameter) aperture in a platinum plate, and also the time taken for the same volume of the gas of unit density to pass through under similar conditions. Then if t seconds be the time taken by the first gas, and t_1 seconds the time taken by the second gas (the density of which is unity), the density of the first gas is equal to $\frac{t^2}{t_1{}^2}$. Bunsen's effusion test for the specific gravity of gas is in practice carried out thus:—A piece of thick walled glass tube, A (Fig. 41), has sealed into its upper end a piece of platinum foil, forming a perfectly air-tight end to the tube, except for a hole of about the diameter mentioned above, in the centre of the piece of foil. The lower part of the tube is ground externally, so as to fit gas-tight into the socket at the top of B. B is a glass of the shape shown, about 12 inches in length, and $\frac{3}{4}$ inch internal diameter, and furnished just below the socket for A with a stop-cock, C. To pass up within it from its open end is a float, D, the total length of which is about 4 inches. Its upper tip, E, is marked with two black lines, about $\frac{1}{16}$ of an inch apart, and just above its lower bulb are two similar lines. There is a line, K, scratched on B about 4 inches from C. Fig. 42 shows a wooden vessel with hollow stalk, and a trough in its upper part, F, into which mercury is poured. The sides of the trough are cut away at G and H, and pieces of glass inserted, so that the level of the mercury in the vessel can be observed through a telescope. The float and the inside of the tube, B, are carefully dried, and the float having been placed in the tube, the latter is filled through the stop-cock, C, with the gas to be examined, which must have been previously dried by passage through calcium chloride. When the tube is filled with the gas, it is pushed down into the mercury in the trough and stem of the vessel in Fig. 42, and the line, K, brought level with the surface of the mercury, the exact adjustment being made under observation through a telescope. The tube, B, is firmly clamped when the proper position is attained. The float will now be entirely below the surface of the mercury. The stop-cock is opened, and the gas being under the pressure of the head of mercury in the trough, passes out through the small hole in the platinum disc of A. The surface of the mercury is carefully observed through a telescope placed level with it at a short

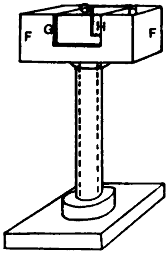

Fig. 42.—Wooden mercury trough for effusion test.

distance from the apparatus. As soon as the upper black line of the float appears at the surface, the second line may be expected, and at the exact moment of its appearance a stop-watch is started. The float continues to rise, and when the upper of the lower pair of lines appears at the surface, the operator stands ready to press the stop of the watch at the exact moment at which the lower line appears. The watch has, therefore, recorded the exact time taken by a fixed volume of gas to pass through the orifice in the platinum disc. The tube is next filled with dry air, and an exactly similar observation made. From the formula already given, and the times of effusion recorded on the stop-watch, the density of the gas compared with air as unity is calculated. Two or three observations should be made, both on the dry gas and the dry air, and the mean time of effusion for each taken for the calculation. The mercury used should be clean and dry, and its surface quite free from dust, &c. The results are very reliable.

N. H. Schilling has proposed a modification of the Bunsen effusion test, in which the tube is larger and water replaces mercury, but as the Bunsen method is sufficiently rapid for most purposes and gives more reliable results, the use of Schilling's design cannot be recommended.

The determination of the specific gravity of gas by direct weighing demands many precautions and the use of a very delicate balance, coupled with considerable skill on the part of the operator. Results obtained by this method with crude apparatus in unskilled hands are valueless. Letheby designed a globe and fittings for carrying out the determination by direct weighing, but as ordinarily made and used the apparatus is of little value. F. Lux's specific gravity balance is intended to show the specific gravity of gas passing through a globe by the indications of a pointer on a scale. Letheby's and Lux's apparatus both require corrections to be made for temperature, pressure, and aqueous vapour.

CHAPTER IX.

PHOTOMETRY.*

Fundamental Law of Photometry.—Photometry is the art by which the ratio between the amounts of light emitted by two sources is ascertained. The physical law that **the intensity of the light received from any source of light varies inversely as the square of the distance from the source** is the basis of the photometric art, and should be always borne in mind when photometrical questions are under consideration. For the exact proof of the law, the form of which is familiar to students of heat and sound as well as of light, the text-books on physics should be consulted. The following demonstration will help the student to comprehend its significance. A source of light, which for simplicity of argument must be considered as a luminous **point**, is situated at the centre of a hollow sphere of radius, r. The total light emitted will be received on the inner surface of the sphere, which is $= 4 \pi r^2$. But if the radius of the sphere be r', the whole of the light will be received on the surface, $4 \pi r'^2$. The same area A on the surfaces of the two spheres will therefore receive $\frac{A}{4 \pi r^2}$ and $\frac{A}{4 \pi r'^2}$ of the total light; that is, an area A at the distance r from the source of light will receive $\frac{A}{4 \pi r^2}$ of the total light, and the same area A at the distance r' from the source of light will receive $\frac{A}{4 \pi r'^2}$ of the total light. But since $\frac{A}{4 \pi}$ is constant, the light received on the area A will vary inversely as the square of the distance (r, r' . . . .). This argument is based on the assumption that the surface of a sphere is $4 \pi r^2$ where r is the radius, the proof of which will be found in any text-book on the geometry of space.

Conditions Requisite for Measuring Light Intensity.—Fortunately no further study of optical science is absolutely

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[*] The illustrations throughout this chapter are kindly furnished by Messrs. William Sugg & Co., Limited, and represent the apparatus supplied by that firm to the official London Testing Stations and to the London Gas Companies.

necessary to the comprehension of photometry. From the first principle enunciated above, the methods adopted are readily derived, and the mechanical devices only serve to apply it more readily to special cases. The measurement of the light from a given source is effected by observing the distance from a given surface at which the source of light must be to give equal illumination on the surface to that afforded by a certain source of light, of arbitrary but unvarying power, at some other observed distance. The measurement of the respective distances of the two lights from the surface when they illuminate it to an equal extent, and the simple application of the law of inverse squares, enable a comparison of the intensities of the two lights to be made. The measurement of the light from a given source thus appears a very simple process, but it will be noticed that the following conditions are directly or indirectly stipulated for in the description of the procedure :—

1. **A standard light,** of uniform intensity, for comparison with the light to be examined. The power of the standard is arbitrarily fixed, but for convenience should bear a known ratio to that of some recognised unit or standard of light, and as a matter of practical working, must be somewhat of the same order of magnitude and of similar tint. Such a standard is not readily obtained, and the use of uncertain standards having a varying intensity has for years discounted the value of photometrical results. The various standards in use will be discussed later.

2. **A means of ascertaining when the Illumination of a Surface by Two Lights is equal.**—In the older photometers, the illumination of two similar surfaces placed side by side, each illuminated by one only of the sources of light, was, by shifting one of the lights, made as nearly as possible equal, or in another variety each light was made to throw a shadow of an object on a screen, and one light moved until the shadows appeared equally dark. These were discarded in favour of a disc more translucent in one portion than in another, the two portions of which become indistinguishable when equally illuminated on both sides. The standard light is, therefore, on the opposite side of the disc to the light under examination. The construction of the disc, and the mechanical device for observing the two sides simultaneously will be described shortly.

3. It is evident that **the illuminated surface or disc must not be subject to illumination from other sources of light** than those under comparison at the time being, and that either by conducting the observations in a darkened room, or by completely screening off the surface or disc from other lights, it must be removed from such influence. Also, the direct rays only from

each light under comparison must fall on the surface; or, in other words, reflection from surrounding surfaces must be abolished.

Personal Equation Error.—When by the use of suitable apparatus and devices, these three conditions have been complied with, there is still an uncertain factor affecting the results, since the equal illumination of two surfaces is judged by the eye. If the lights are of similar tint, this element of uncertainty may be negatived by making a considerable number of comparisons; the mean of the results will approximate very closely to the truth, since, *cæteris paribus*, there is no reason why the errors in observation should favour one source of light more than the other. But where the lights compared are of widely different intensities, or of different tints, equal illumination is not readily judged, and the personal equation of the operator is a very potent factor in determining the results. The cases comprised under the usual methods of examining ordinary coal gas should not be greatly affected by differences of judgment on the part of operators as to what constitutes equal illumination of the screen or disc used. The judgment is nevertheless easily perverted by apparently trivial influences, most of which, however, may be guarded against by a conscientious observer.

Standard Gas Burner.—For observing the illuminating power of coal gas several conditions as to the method of burning it must be observed. To give gas its full value, the burner and rate of consumption most suited to it should be used, and these can only be experimentally determined for any particular gas. For testing the quality of gas, Argand and flat-flame burners only are used; regenerative and incandescent burners would give very different results, and for the present are not regarded as suitable for estimating the quality of gas, though admittedly they develop a higher lighting effect from it than others. Speaking very generally, the Argand burner gives the best results with gas up to about 18 candle power,* and flat-flame burners of various sizes with gas above that power. Under certain conditions, however, richer gases may be burnt in Argand burners with good results. The pressure and the rate of consumption of the gas affect its illuminating power, and hence in any testing of the lighting value of gas these must be regulated and observed. The most general case of gas examination will be that of gas of 16 candle power or thereabouts, and the regulations of the Metropolitan Gas Referees for testing the gas of the Metropolis, which is required to be of not lower value than 16 candle, will serve to show the method in which such gas is burnt for testing purposes.

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* The candle here referred to is the standard English sperm candle, defined on p. 226. Where not otherwise qualified, "candle" is used throughout this work in that sense.

The burner is described by the Referees as follows :—

"The burner which has been adopted as the standard burner for testing common gas was designed by Mr. Sugg, and was called by him 'Sugg's London Argand, No. 1.' A half-scale section is appended (Fig. 43), in which A represents a supply pipe, B the gallery, C the cone, D the steatite chamber, E the

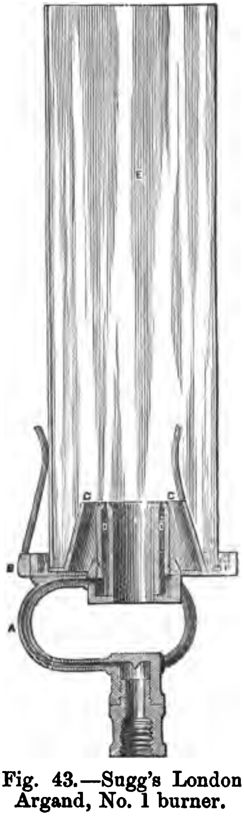

Fig. 43.—Sugg's London Argand, No. 1 burner.

A, Supply pipe; B, gallery; C, cone; D, steatite chamber; E, chimney.

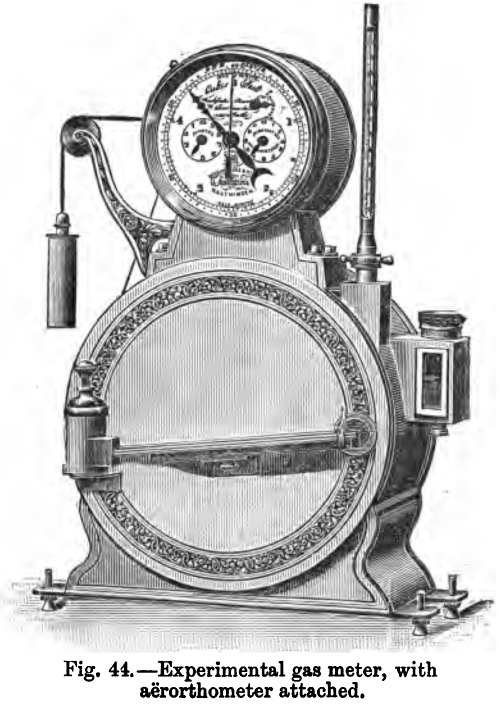

Fig. 44.—Experimental gas meter, with aërorthometer attached.

chimney. The following are the dimensions of those parts of the burner upon which its action depends:—"

	Inches.
Diameter of supply pipes,	0·08
External diameter of annular steatite chamber,	0·84
Internal diameter of ,, ,, ,,	0·48
Number of holes,	24
Diameter of each hole,	0·045
Internal diameter of cone—	
At the bottom,	1·5
At the top,	1·08
Height of upper surface of cone and of steatite chamber above floor of gallery,	0·75
Height of glass chimney,	6
Internal diameter of chimney,	1⅞

Experimental Meter.—The pressure of the gas, if excessive or subject to considerable variations, should be controlled by a governor of some ordinary pattern on the supply pipe. Dry governors having a leather diaphragm are often used in this position. The gas passing to the testing burner is then measured in a small experimental meter. This is illustrated in Fig. 44. It consists of a small wet meter of the simplest construction, provided with a glass-fronted case on one side, by means of which the water level can be at any time observed. An opening in the top of this case permits the addition of water to raise the water level to the normal (indicated by a line on the glass front); a screw cap with leathern washer closes the opening when the adjustment of water level is duly made. The indications of the meter will be fallacious if the water is not at the proper level. The meter is of such a capacity that one complete revolution passes one-twelfth of a cubic foot of gas. Each revolution of the drum is indicated by one complete revolution of the pointer on the large dial of the meter. This dial is graduated into five major divisions, each indicating one-fifth of the complete revolution of the drum, and therefore one-sixtieth of a cubic foot. These divisions are each subdivided into tenths. A small dial divided into twelve equal divisions, each representing one revolution of the pointer on the large dial, records the number of these revolutions up to twelve, the number indicating the passage of one cubic foot of gas through the meter. The experimental meter contains further a small clock having the spindle of the seconds hand set co-axially with the spindle of the meter pointer on the large dial. The clock is wound by means of the cord on the left of the meter, the weight giving the motive power to it when in action. The clock can be started and stopped at any moment by means of a small slide, and when in action it rings a bell each time the hand passes the uppermost mark on the dial—that is to say, at intervals of one minute. This clock enables the rate of passage of the gas to be readily observed, and the meter indices are specially graduated to facilitate the rapid observance of rates of 5 cubic feet per hour and thereabouts. This is the rate at which ordinary 16-candle gas is consumed for testing purposes in the standard Argand burner. The seconds hand of the clock is arrested at the uppermost graduation of the dial, and is re-started as the meter pointer passes that graduation. When the bell rings, indicating the expiration of one minute, the position of the meter pointer is observed. If the rate of passage of the gas is exactly at 5 cubic feet per hour, the meter pointer will have exactly completed its revolution, and the pointer and the clock hand will have revolved at exactly the same rate. This is clear, since one-twelfth of a cubic foot per minute is the same rate as 5 cubic feet per hour. The system of graduating the dial enables the exact rate, even when it is not the normal, to be read off at a glance in feet and tenths of a foot per hour, by an observation extending over one minute. As a matter of fact, the clock is kept running during the period of testing, and the position of the pointer observed at intervals of a minute, so that a record of any variation in the rate of passage of the gas is kept. Near the water-level gauge is a thermometer, the bulb of which is in contact with the gas within the meter, while the stem protrudes for ready observation.

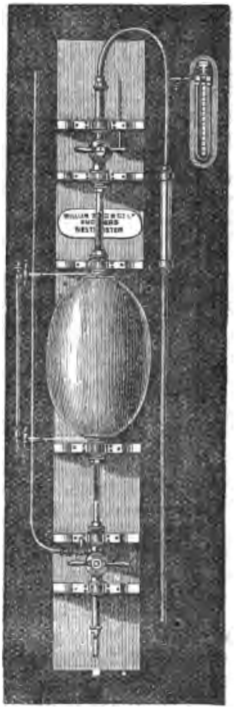
Fig. 45.—Cubic foot measure.

Cubic Foot Measure.—The experimental meter used for photometrical purposes, and also the meter used for sulphur and ammonia determinations, are best tested for accuracy by the cubic foot measure of the Metropolitan Gas Referees. This instrument is shown in Fig. 45. The following are the instructions issued by the Referees for the testing and adjusting of meters by means of this instrument:—

DESCRIPTION OF THE CUBIC-FOOT MEASURE, THE METHOD OF FIXING IT, AND DIRECTIONS FOR VERIFYING THE ACCURACY OF THE METERS CONNECTED WITH THE PHOTOMETER AND WITH THE SULPHUR AND AMMONIA TESTS.

This instrument is a vessel of a cylindrical form, with rounded ends, made of hardened tin about ¼ inch thick, fitted at each end with a glass tube—the joints being made sound with indiarubber packing. The instrument stands in a vertical position firmly fixed to a strong plank.

At the top of the instrument is a three-way cock, marked on the head of the key with a T, each arm of which shows the direction of a way through the plug; and attached to the side of this cock there is a small pipe, which serves to admit gas when the measure is to be charged. When the T is in its ordinary position communication is closed between the measure and the tube leading from it to the meters, but is open to the gas supply; with the ⊣ in this position (*i.e.*, with the stem pointing to the *opposite* side of the cock to that connected with the gas supply) the measure is open to the meters and shut to the gas.

At the bottom of the instrument there are three cocks—one large and two small ones. One of the small ones, when opened, admits water into the measure; the other small one is used for verifying the adjustment of the measure, by discharging the water into a standard measure. The large cock, when opened, allows the water to run off.

The cock at the top of the measure is continued by a tin pipe which rises above the level of the water in the cistern, and then returns downwards, passing to the two meters.

Affixed round the glass tubes fitted to the upper and lower part of the measure there are narrow strips of paper, which indicate the exact measure of 1 cubic foot.

The instrument should be in communication with a tank of water in the same room.

To verify the meters employed in ascertaining the consumption of gas in the photometers, or those employed in the sulphur and ammonia tests, the mode of procedure is as follows:—

Starting with the bottle full of water, turn the three-way cock at the top of the instrument, so as to place the measure in communication with the gas supply from the main, and open the large cock at the bottom of the apparatus. When the bottle is filled with gas to below the water line, close the large cock, and turn the upper three-way cock, so as to close the inlet for gas, while opening the way to the meters.

Next, turn the cock of the meter which is to be tested, so as to cut off the ordinary gas supply, and to place the meter in communication with the cubic-foot measure, taking care that all the other meters are closed to the cubic-foot measure. See that the tap is open which allows gas to pass from the meter, through the governor, to the burner.

Then proceed gently to open the small lever-cock, and allow water to flow into the measure, sufficient to fill the lower glass tube up to the water line. Note the exact position of the index hands.

Now turn on the lever-cock, watching the pressure gauge attached to the measure, until gas is passing through the meter at about the normal rate of 5 cubic feet an hour. When the measure is nearly full, stand by to check the rate of flow, and finally shut the water off as it reaches the upper water line. Read the meter.

Should the meter have completed more than the prescribed number of revolutions when the measure is full, then some water must be removed from the meter; if the contrary is the case, then water must be added to the meter. The testing is then to be repeated until the meter is found to register correctly.

The dial of the photometer-meters is divided into fifty divisions; and as each revolution indicates $\frac{1}{12}$ of a foot, each division, consequently represents the $\frac{1}{600}$ part of a cubic foot; and, therefore, six of those divisions represent $\frac{1}{100}$ part of a cubic foot.

The dial of the sulphur meters is divided into 100 parts; and as each complete revolution indicates 1 foot, each division, consequently, represents 1 per cent. of the volume sent through.

For accurate measurement it is essential that the temperature of the gas in the measure and that in the meter should be the same. If the temperature of the water with which the measure has been filled is different from that of the meter, a sufficient time must be allowed to elapse after the measure has been filled with gas, for the measure to have gained the temperature of the surrounding air. The measure and the meters must be so placed that the temperature of the air which surrounds them is the same.

Balance Governor.—From the experimental meter the gas passes into a small governor, which works on the principle of the large governors described in a previous chapter. The bell is attached to one arm of a balance beam, to the other arm of which is attached a cord for the support of weights. By the addition of weights to this arm and by their removal the pressure at which the gas issues from the governor is controlled to a nicety, and can be maintained constant at any desired amount. This form of balance governor is illustrated in Fig. 46.

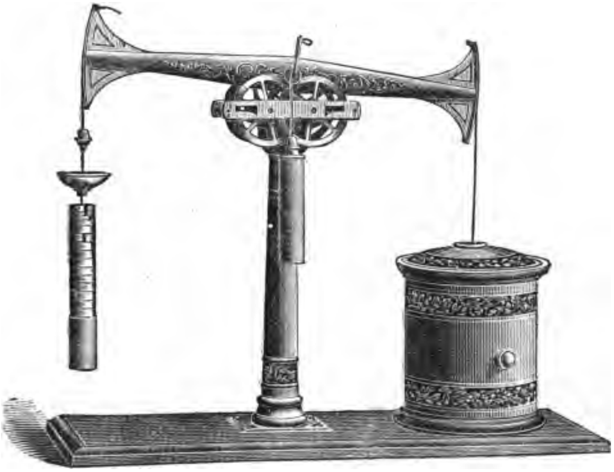

Fig. 46.—Balance governor.

King's Gauge.—The pressure at this and other points in the train of apparatus leading to the burner is ascertained by a special form of pressure gauge, which is connected to four points of the apparatus, from any of which the gas can be brought to it by merely turning on one tap, all the others being at the time shut to the gauge. The instrument, known as King's gauge, consists of a float to which is attached a cord wound once round a spindle mounted on friction wheels, a small balance weight being secured to the other end of the cord. The spindle actuates a pointer passing over a graduated semi-circular scale. The slightest variation in the pressure of the gas is recorded by the movement of the pointer over the scale. For photometrical use this gauge usually ranges from zero to $1\frac{1}{2}$ inches, and is divided into $\frac{1}{100}$ of an inch. It is shown in Fig. 47. The inlet can be thrown open to either the inlet of the meter, the inlet of the governor, the outlet of the governor, or the burner supply pipe. A blow-off tap is also provided on the inlet. The water level in the gauge must be maintained constant; a plug is fitted to the tank, and the water should be poured in until it begins to overflow at this plug-hole. After the height of the water has been regulated, the pointer must be placed at zero, the inlet being opened to the air by means of the blowoff tap, and the outlet tap also being open. The pressure should be taken off the gauge once a day when it is in regular use, and the pointer adjusted if it does not return to the zero mark of its own accord.

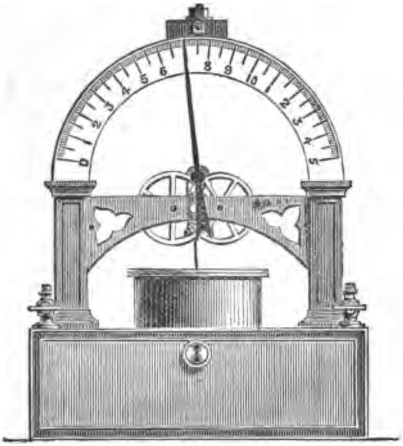

Fig. 47.—King's gauge.

Burner.—The gas passes from the governor direct to the burner, but its rate of flow is controlled by a regulating cock, which can be adjusted to a nicety. This is often simply a well made cock with a long lever handle, sometimes the end of the lever passes in front of a quadrant scale, and for very exact adjustment is moved by means of a screw. Between this cock and the burner an ordinary tap is often inserted, so that the gas may be turned on or off without moving the regulating cock, and giving need for its careful readjustment. The burner for ordinary 16 candle coal gas, which is the official standard in London, and is very generally used throughout the country, has been described on p. 217. Burners for other descriptions of gas will be briefly noticed later.

Photometer.—The photometer table which carries the disc and graduated scale, and the accessory apparatus which, with it, form what is generally known as the photometer, may be of somewhat varied design, but the essential parts of an ordinary fixed photometer are now becoming of fairly stereotyped shape and dimensions, and, broadly, two patterns only need be considered. These are the improved forms of the Bunsen photometer, known as "Letheby's open 60-inch photometer," and "Evans' enclosed 100-inch photometer." The first is shown in Fig. 48. The distance between the standard light and the burner in this instrument is 60 inches. The positions of the standard and of the gas burner are determined by plumb lines, supported at the proper distance apart by the top of the instrument. A screw adjustment can be used for moving the standard when required, and great precision is thereby secured. Circular holes, 6 inches in diameter, are cut in the top of the photometer, above the lights, for the ready removal of the hot and vitiated air. The disc carrier travels on small wheels along

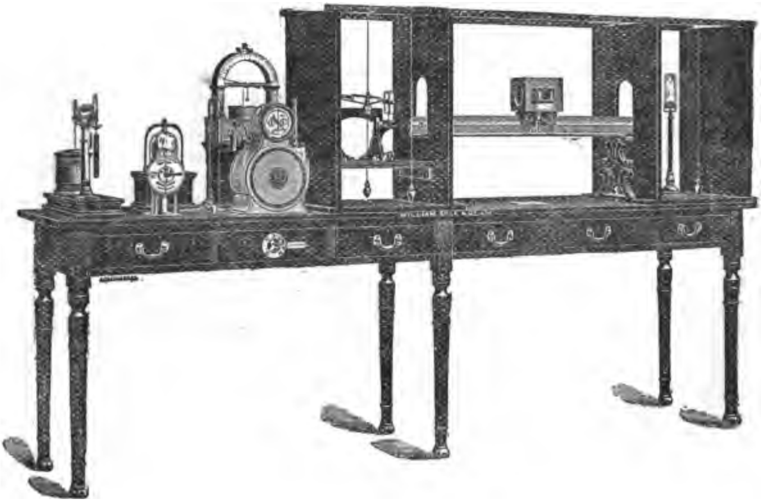

Fig. 48.—Letheby's open 60-inch photometer.

the bar, which is provided with a carefully graduated scale. This scale may be an ordinary linear measure graduated in inches, but is more often graduated in accordance with the principle of inverse squares, the standard light being considered of unit value. If the standard has some other value, the readings on the scale must be multiplied accordingly to get the correct value in terms of the unit. The disc is mounted on one of the reversible holders illustrated in Fig. 50. The scale is in darkness while the disc is under observation, but is illumined by a ray of light from the gas burner on drawing aside a curtain. This form of photometer is approved by the Metropolitan Gas Referees, and can be obtained with the stamp of the Board of Trade Standards Department.

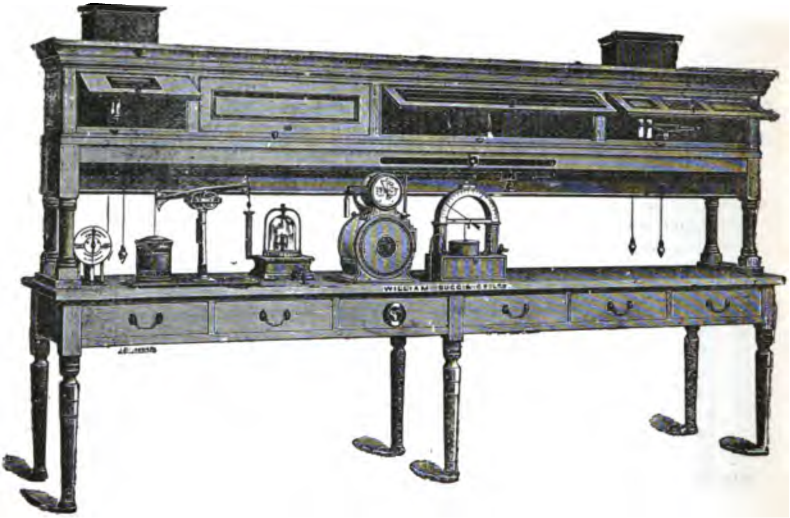

Fig. 49.—Evans' enclosed 100-inch photometer.

The "Evans' enclosed 100-inch photometer" is also approved by the Metropolitan Gas Referees, and may be obtained certified by the Board of Trade. It is shown in Fig. 49. In this instrument, the flames and disc carrier and screens are enclosed in a well ventilated case with glazed flaps in front. The carrier has a pointer attached to it, which passes through the bottom of the case and travels over a scale placed underneath. The case protects the flames from slight draughts. A black canopy is provided in front of the disc carrier, so that an observation may be taken in an imperfectly darkened room. In other respects, the fittings are very similar to those of the previously described instrument.

Disc.—The disc, on which the comparison of the lighting effects is made, may be of either of two kinds. One, the Bunsen, originally consisted of a piece of paper, having a circular grease spot in its centre. As now made, the relative positions of the greased and ungreased portions of the paper are reversed; an ungreased spot of about 1 inch diameter is circumscribed by the carefully greased paper. The greasing is now generally effected with melted sperm, and the paper is thick. The other disc, known as the "Leeson," consists in its latest improved form of three pieces of paper, of which the middle thicker piece has a star-like hole cut around its centre. The pieces are then moistened with dextrin, pressed closely together, and dried under pressure. The principle on which the use of the disc depends is the same with either kind; the two portions of the disc have a different translucency, and hence, if the disc is illuminated more strongly on one side than on the other, one portion of it appears darker than the other. When the illumination is equal on both sides, the two portions of the disc should be nearly indistinguishable. The Bunsen disc is more generally used in ordinary photometrical work; the "Leeson," however, gives the best results when lights of different tints are under comparison. The disc is mounted in a frame, pivoted on each side so that it turns about a horizontal axis drawn through its centre. The disc is then reversed by merely turning the frame over, and this reversal should be made once in every series of readings for a single test. If the two sides of the disc do not give precisely coincident results, the error is minimised by the reversal of the disc half way through each testing, so that half the readings are taken with each side; though, if there is a really perceptible discrepancy between the results with the two sides, the disc should be at once discarded, and another one used after due trial. In Dibdin's **reversible-disc holder**, shown in Fig. 50, the mirrors which present images of the two sides of the disc simultaneously to the eye are fixed on the revolving frame, and are turned round with the disc. If the mirror on one side causes greater loss of brilliancy than that on the other, the reversal of the mirrors with the disc nullifies the effect of the inequality on the tests.

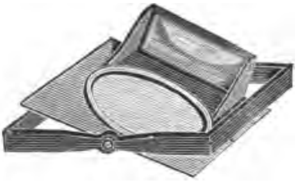

Fig. 50.—Dibdin's reversible disc holder.

In this connection it may be pointed out that though the two forms of disc here described and the method of mounting them are those adopted in this country for gas testing to the practical exclusion of all others, it is open to question if they are really the most suitable. It has been argued by Continental photometrists with great plausibility that the line of demarcation between the greased and ungreased portions of the disc should be a straight line bisecting the horizontal line drawn between the two sources of light. They, therefore, propose to use a disc consisting of a greased and ungreased rectangle, so set that the line of demarcation is vertical and passes through a straight line drawn between the two lights. Such a disc is theoretically susceptible of more exact observation than the Bunsen or Leeson, and a number of trials showed that it yielded more concordant results. The method of setting the mirrors has often been discussed, but it appears that two mirrors set one on each side of the disc at an angle of 60 degrees to it is not to be improved upon. The revolution of the disc compensates for discrepancies due to a difference between the two sides of it, but to compensate for unequal receptivity of the eyes of the observer, it is necessary to read alternately from each side of the photometer, a procedure not adopted in this country. In this work it is, however, for the sake of conciseness, assumed that the methods and instruments prescribed by the Metropolitan Gas Referees are sufficiently exact for general gas testing, and the refinements of the art will not be discussed at length.

Standard Light.—The photometer and accessory apparatus have now been described, with the exception of the standard light. In this country this is either the "standard candle" itself, or some substitute which has an illuminating power bearing a known simple ratio to that of the standard candle. The standard candle is defined by the Metropolis Gas Act of 1860, section 25. Thereby standard candles are "sperm candles of six to the pound, each burning 120 grains per hour." The Act does not define them further, unfortunately, and it has been found possible to make candles of varying illuminating power which fall within this definition. The candles supplied by two firms for some time past have been of very uniform illuminating power, and were generally accepted as the standard, but a short time ago the London County Council obtained candles agreeing with the above definition, and complying with the stipulations of the Gas Referees, which had a considerably higher illuminating power than those formerly used. The use of the new candles in the official testing stations in the Metropolis was soon stopped, as a higher illuminating power was yielded by them than by those which for years had been accepted as standard candles, and the Metropolitan Gas Referees issued instructions for the examination of the candles, and undertook to examine all batches of candles for use in the official testing stations. The candle as now certified by the Referees may, therefore, be considered representative of the standard candle of the Act, as universally understood for some years past. This is fortunate, as an alteration in the value of the standard candle would render the labour and researches of years in the preparation of other standards of light and of reference tables comparatively valueless. The instructions which were issued in 1894 by the Referees for the preparation and examination of the candles are given on p. 238. For the present the candle may be taken to be that which was understood prior to 1893 as a standard candle, and the method of using it in the photometer for gas testing may be considered at once.

Candle Balance.—It is evident that candles, however carefully constructed, cannot be made to uniformly burn exactly 120 grains of sperm per hour. The Gas Referees assume that the illuminating power of a candle varies strictly as the rate of consumption of the sperm for variations of not more than 6 grains per hour above or below the normal rate, and make correction accordingly. If the rate of consumption of a candle exceeds 126 grains or falls short of 114 grains per hour, any testing made with it must be discarded. It will be seen, therefore, that it is necessary to have a ready means of observing the rate of consumption of a candle while it is actually being used for testing purposes. This means is provided in the ordinary candle balance, which is designed for weighing the candles while they are in position and alight in the photometer. The candle balance has undergone many modifications since Keates brought it into general use. His balance was constructed on the steelyard principle, the candles being on the shorter arm, and balanced by weights on the longer arm. One modification of this has a screw thread on which travels a weight cut on the longer arm for facilitating the ready counterpoising of the candles. In practice the candles are nearly counterpoised by placing sufficient shot in the pan beneath them to depress that arm of the balance; when it rises a 40-grain weight is placed in the pan, and the time that elapses before the pan again rises (40 grains of sperm having been consumed in this period) is observed. Since two candles are used, 40 grains of sperm will have been consumed in ten minutes at the normal rate of 120 grains of sperm per candle per hour. The extreme variations allowed by the Referees are represented by the pan

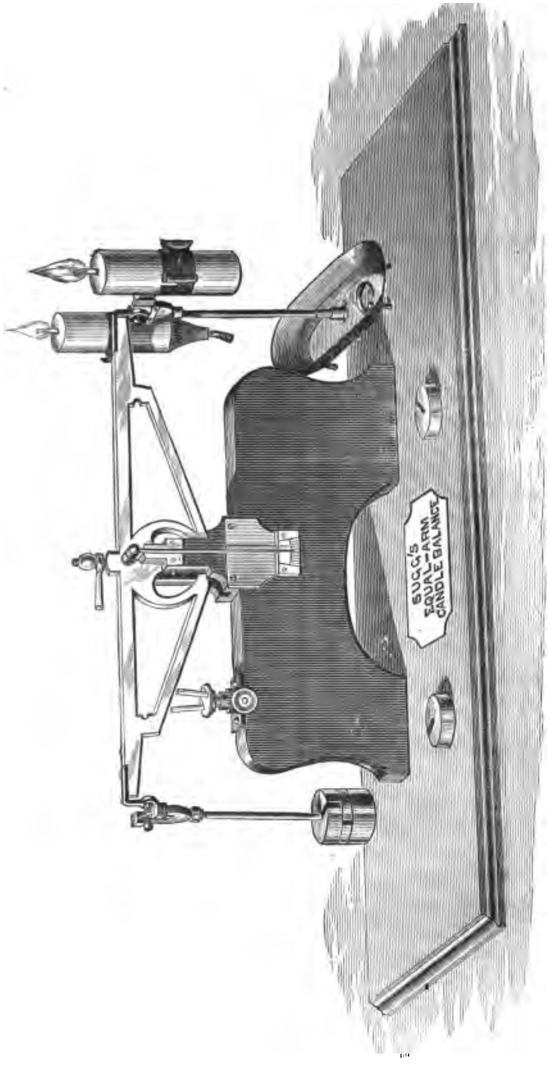

Fig. 51.—Sugg's equal-arm candle balance.

rising in nine and a-half and ten and a-half minutes. One of the most convenient of the recent forms of candle balance is Sugg's equal-arm, shown in Fig. 51. The 40-grain ring-counterpoise weights supplied for candle balances should invariably be tested on a delicate and reliable balance against correct weights, as they are often $\frac{2}{10}$ or $\frac{3}{10}$ of a grain above or below the correct weight.

The method of making a test of illuminating power on ordinary coal gas may be best illustrated by giving the instructions issued by the Gas Referees to the gas examiners at the official testing stations in the Metropolis, which run as follows:—

"Times and Mode of Testing for Illuminating Power.

"The testings for illuminating power shall be three in number daily. But if the average of three testings of illuminating power falls below the prescribed illuminating power, a fourth testing shall be made. It is required (Gaslight and Coke and other Gas Companies Acts Amendment Act, 1880, section 7) 'that the tests for illuminating power shall be taken at intervals of not less than one hour.' Also (section 8), 'the average of all the testings at any testing place on each day of the illuminating power of the gas supplied by the company, at such testing place, shall be deemed to represent the illuminating power of such gas on that day at such testing place.'

"The photometers to be used in the testing places shall be the improved forms of the Bunsen photometer, prescribed and certified by the Referees.

"The burner attached to each photometer shall be a standard burner, corresponding to that which has been deposited with the Warden of the Standards, in accordance with section 37 of the Gaslight and Coke Companies Act, 1876. A description of the standard burners to be used for testing common gas is given on p. 217.

"The gas in the photometer is to be kept burning for at least fifteen minutes before any testing is made; and no gas shall pass through the meter, attached to the photometer, except that which is consumed by the standard burner in testing or during the intervals between the testings made on any day.

"The disc used in the photometer shall be either the improved Leeson or the Bunsen disc. When a disc is not in use, it should be covered to protect it from dust; and if a disc is in any way marked or soiled, a clean disc is to be substituted.

"A clean chimney is to be placed on the burner before each testing.

"The candles shall be such as are prescribed on p. 238. Two of these candles, or two of the half-candles formed by cutting one of these candles in two, shall be used together. The three testings made on one day shall be made with three different pairs of candles or half-candles.

"Each testing shall consist of ten observations of the photometer, made at intervals of one minute. When five observations have been made, the disc and mirrors are to be reversed by being turned round through half a circle. The average of each set of ten observations is to be taken as representing the illuminating power for that testing.

"The rate of burning of the gas in each burner shall be 5 cubic feet per hour—a rate of consumption which is shown by the long hand of the meter making exactly one revolution per minute for several minutes consecutively.

"The candles are to be lighted at least fifteen minutes before the beginning of each testing, so as to have attained their normal rate of burning. The gas examiner may ascertain whether the candles are burning at nearly the normal rate, by placing a 4-grain weight in the candle-pan when the balance turns, and observing whether the balance turns again after the lapse of one minute. Before each testing, the two candles are to be so placed that the plane of the curvature of one wick shall be perpendicular to the plane of the curvature of the other wick, and the candle-balance is to be so adjusted that the axes of both flames shall lie exactly between the two plumb-lines which mark the position of the zero of the scale.*

"Before and after making each testing the gas examiner shall counterpoise the candles; and if the rate of consumption per candle shall not have exceeded 126 grains per hour, or fallen short of 114 grains per hour, he shall make, and record in a book to be kept for the purpose, the calculations requisite to neutralise the effects of the divergence from 120 grains per hour. If the rate of consumption shall have varied from the prescribed rate beyond the above-named limits; or if the gas examiner should observe, during the testing, that the candles are burning irregularly, or that their flames are not exactly between the two plumb-lines, the testing is to be rejected, and a fresh testing made.

"Instead of weighing the candles, the gas examiner may observe the time in which 40 grains are burnt. This must not exceed 10·5, or fall short of 9·5 minutes.

"The gas examiner shall, at least once a week, compare the meter-clock with the standard clock in each testing place.

"At the time of each testing the gas examiner shall observe and record the temperature of the gas, as shown by the thermometer attached to the meter, and also the height of the barometer. The volumes of the gas operated upon during the testings may be corrected from these data (the standard of comparison being—for the barometer, 30 inches; and for the thermometer, 60°) by means of the table given on p. 236. Suppose, for example, the thermometer stands at 54°, and the barometer at 30·3 inches—multiply the quantity of gas consumed by the corresponding *tabular number*—the product will be the corrected volume of the gas—*i.e.*, the volume the gas would have occupied when measured over water at the standard temperature and pressure. Thus:—

Volume of gas consumed, ...	5 cubic feet.
Tabular number for barometer and thermometer, ...	1·025

Then 1·025 × 5 = 5·125 the corrected volume.

"Instead of thus correcting the volume of gas consumed, the same object may be attained by dividing the observed illuminating power by the tabular number, or in the manner described on p. 203, or by multiplying the observed illuminating power by the reading of the aërorthometer.

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* "This direction refers to the form of photometer prescribed by us in all recently established testing places, namely, a photometer having the position of the candles fixed and the disc movable, and does not apply to those box photometers in which the disc is fixed and the candles are movable."

"The gas examiner shall enter in his book the particulars of every testing of illuminating power made by him at the testing places during, or immediately after, such testing; and, in the case of any testing which he rejects, he shall also state the cause of rejection. No testing is to be rejected on the ground that the result seems improbable."

"The calculations for working out the corrections, &c., for the illuminating power of the gas proceed in the following manner:—Add the observations together, and divide the sum by ten to get the average; then, as two candles are used, multiply by two, to get the illuminating power of the gas if tried against one candle. Then, as the standard rate of consumption of the candles (viz., 120 grains) is to the average number of grains consumed by each per hour, so is the above-obtained number to the actual illuminating power. Finally, make the correction for temperature and pressure by dividing the illuminating power by the tabular number. For example (taking the tabular number as 1·025):—"

Observations—

1st minute, ...	7·8
2nd ,, ...	7·8
3rd ,, ...	8·1
4th ,, ...	8·2
5th ,, ...	8·3
6th ,, ...	8·5
7th ,, ...	8·6
8th ,, ...	8·4
9th ,, ...	8·3
10th ,, ...	8·6

Consumption of the 2 candles
in 10 minutes,
= 41 grains.
3
123 = Consumption of
1 candle per hour.

	10)82·6
Average by 2 candles = . .	8·26
	2
Average by 1 candle = . .	16·52
Consumption by 1 candle per hour	123 grains.
	4956
	3304
	1652
Standard consumption, .	120)203196
Correction for tem. and pres.,	1025)16933(16·5 = Corrected illum. power in candles.
	1025
	6683
	6150
	5330

The foregoing calculation can be shortened as follows:—

Observations—

1st minute,	7·8
2nd "	7·8
3rd "	8·1
4th "	8·2
5th "	8·3
6th "	8·5
7th "	8·6
8th "	8·4
9th "	8·3
10th "	8·6
	82·6

Consumption by 2 candles in 10 min. 41 grains.

826
3304

2)33866

Tabular number, . . 1025)16933(16·5 = Corrected illum. power in candles.
1025

6683
6150

5330

If, instead of observing the number of grains of sperm consumed in ten minutes, the time taken for the consumption of 40 grains is found, the calculation given in the Referees' example could be altered accordingly. Instead of multiplying by the number of grains consumed by the two candles in ten minutes and dividing by 2, divide by the number of minutes in which 40 grains were consumed. Thus, if 40 grains were consumed in 9 minutes 45 seconds = 9·75 minutes, the calculation would be:—

9·75)82·6 (8·47 = Average by 2 candles.
7800

4600
3900

7000
6825

·175

8·47
2

Average by 1 candle = . . 16·94
Tabular number = . . . 1025)16·94(16·5 = Corrected illum. power in candles.
1025

6690
6150

·540

Little need be added here to the explicit instructions of the Referees to make them applicable to all ordinary cases of gas testing. The gas pipes under the photometer table are provided at their lowest points with small taps, which should be opened occasionally to allow of the escape of any water condensed from the gas. A good clock with seconds hand and stop action is needed for timing the consumption of sperm in the candles. The clock should be stopped with the seconds hand at 0, and started as the pointer of the candle balance passes the middle mark on the scale; the 40-grain weight is quickly added to the pan of the balance, and the clock is stopped again when the pointer again travels over the middle point of the balance scale. The time in which 40 grains of sperm is consumed is thus obtained with great exactness. The pressure of the gas as shown by the King's gauge at the outlet of the balance governor should be from 0·6 to 0·8 of an inch of water. The whole of the apparatus should be kept clean, but especially the glass chimney of the burner and the candle balance. The meter and clocks should be tested for accuracy once a week. The Referees' directions as to the disposition of the candles, so that the planes of curvature of the wicks are at right angles to one another, should be rigidly observed; no test should be taken until the candles have been burning for at least fifteen minutes, and especial care should be taken to place the candle balance so that the flames have their axes in the plane of the two plumb-lines which are at the zero point of the scale. Many photometers are provided with a sensitive screw adjustment for accurately placing the candle balance. The two halves of one candle are usually used side by side for the same test; the candle is cut across midway, and the sperm pared away from the wick ends so exposed until they can be lighted. Care should be taken that the wicks are not cut or injured in removing the sperm from around them. No use should be made of the conical top portion of the candle.

The Aërorthometer.—The aërorthometer mentioned in the Referees' instructions is an instrument invented by A. Vernon Harcourt to show at a glance the volume which 1,000 volumes of a gas under normal temperature (60° F.) and pressure (30 inches) assume under the conditions of temperature and pressure obtaining in the atmosphere at the time. The instrument is shown in Fig. 52. It consists of a small-bore glass tube terminating at its upper end in a closed bulb, and at its lower end in a reservoir of mercury. Alongside is another similar tube, which, however, is without the bulb and unclosed at its upper end. The reservoir is enclosed in a wooden case, and it can be readily compressed to drive mercury up the tubes by screwing down the small milled screw on the top of the foot of the instrument. The bulbed tube is in the first instance filled with a volume of air which at 30 inches pressure and a temperature of 60° F. brings the top of the mercury column in the tube exactly to the mark 1,000 on the scale. The scale is marked in such a manner that at any other temperature and pressure the height of the mercury in the bulbed tube indicates on the scale the volume of gas at that temperature and pressure corresponding to 1,000 under normal conditions. There is sufficient moisture in the bulbed tube to saturate the contained air under all conditions within the range of the instrument, hence no correction is needed for the tension of aqueous vapour in using the readings of the instrument for correcting the volumes of moist gases. When in use the instrument should be

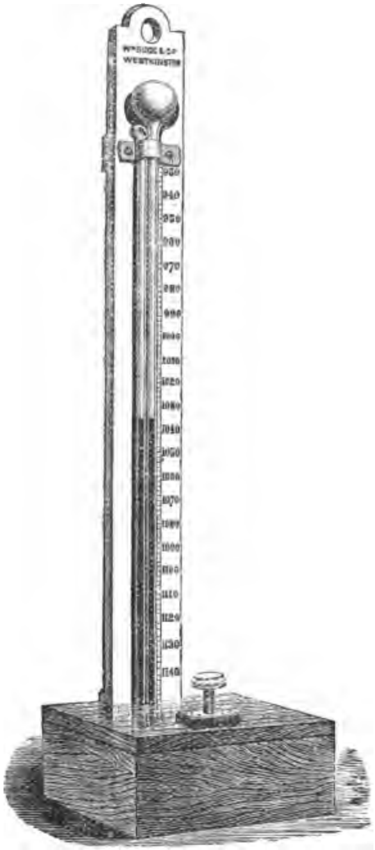
Fig. 52.—Harcourt's aërorthometer.

stood near the vessel (meter or holder) containing the gas, the volume of which is required under normal conditions. To take a reading, the level of the mercury in the open tube is depressed by raising the milled screw until it is below that of the mercury in the bulbed tube. The screw is then turned down gradually until the mercury stands at precisely the same level in both tubes. The corresponding figure on the scale gives the volume under the conditions of temperature and pressure obtaining at the time of 1,000 volumes of gas under normal temperature and pressure. The tension is the same within the bulbed tube as outside when the mercury stands at the same level in both tubes. The numbers read on the scale serve at once for the calculation of the volumes of gases under normal conditions from volumes observed under other conditions. The corrected volume of gas is found by multiplying the observed volume by 1,000 and dividing by the aërorthometer reading. Or, in correcting the illuminating power of gas, the aërorthometer reading is used as a multiplier of the observed illuminating power, as stated in the Referees' instructions. The aërorthometer is made in slightly different form for attachment to the case of an experimental meter, as shown in the illustration of a meter on p. 217.

Tabular Numbers.—The tabular numbers referred to in the Referees' instructions are taken from a table issued with them of which that on pp. 236 and 237 is a reprint.

Standard Light.—It may be observed that the use of two candles as the standard of the measurement of the light as prescribed by the Referees is open to the obvious objection that it entails a deliberate departure from the point of light which by theory is the only permissible standard. As, however, the light of one candle does not issue from a point, but from an extended surface, the error is not considerably greater when two candle flames are used side by side. It would, however, in view of the fact that the light of the standard does not issue from a point, but from a comparatively large surface, be an improvement to keep the distance between the standard light and the disc constant, and to make the comparison by moving the light under examination, instead of the disc as is at present done. Some of the systems of photometry in vogue on the Continent maintain this constant distance between the standard light and the disc, and, therefore, constant illumination of one side of the latter by the standard. The Referees' method is, however, that generally used here.

The following is the text of the prescriptions of the Gas Referees of the Metropolis with regard to the examination and

TABLE TO FACILITATE THE CORRECTION OF THE VOLUME OF GAS AT

BAR.	THER. 40°	42°	44°	46°	48°	50°	52°	54°	56°	58°	60°
28·0	·979	·974	·970	·965	·960	·956	·951	·946	·942	·937	·932
28·1	·983	·978	·973	·969	·964	·959	·955	·951	·945	·941	·936
28·2	·986	·981	·977	·972	·967	·963	·958	·953	·949	·944	·939
28·3	·990	·985	·980	·976	·971	·966	·961	·957	·952	·947	·942
28·4	·993	·988	·984	·979	·974	·970	·965	·960	·955	·951	·946
28·5	·997	·992	·987	·983	·978	·973	·968	·964	·959	·954	·949
28·6	1·001	·995	·991	·986	·981	·977	·972	·967	·962	·958	·953
28·7	1·004	·999	·994	·990	·985	·980	·975	·970	·966	·961	·956
28·8	1·007	1·003	·998	·993	·988	·984	·979	·974	·969	·964	·959
28·9	1·011	1·006	1·001	·997	·992	·987	·982	·977	·973	·968	·963
29·0	1·014	1·010	1·005	1·000	·995	·990	·986	·981	·976	·971	·966
29·1	1·018	1·013	1·008	1·004	·999	·994	·989	·984	·979	·975	·969
29·2	1·021	1·017	1·012	1·007	1·002	·997	·992	·988	·982	·978	·973
29·3	1·025	1·020	1·015	1·011	1·006	1·001	·996	·991	·986	·981	·976
29·4	1·028	1·024	1·019	1·014	1·009	1·004	·999	·995	·990	·985	·980
29·5	1·032	1·027	1·022	1·018	1·013	1·008	1·003	·998	·993	·988	·983
29·6	1·036	1·031	1·026	1·021	1·016	1·011	1·006	1·001	·996	·992	·986
29·7	1·039	1·034	1·029	1·025	1·019	1·015	1·010	1·005	1·000	·995	·990
29·8	1·043	1·038	1·033	1·028	1·023	1·018	1·013	1·008	1·003	·998	·993
29·9	1·046	1·041	1·036	1·031	1·026	1·022	1·017	1·012	1·007	1·002	·997
30·0	1·050	1·045	1·040	1·035	1·030	1·025	1·020	1·015	1·010	1·005	1·000
30·1	1·053	1·048	1·043	1·038	1·033	1·029	1·024	1·019	1·014	1·009	1·003
30·2	1·057	1·052	1·047	1·042	1·037	1·032	1·027	1·022	1·017	1·012	1·007
30·3	1·060	1·055	1·050	1·045	1·040	1·036	1·030	1·025	1·020	1·015	1·010
30·4	1·064	1·059	1·054	1·049	1·044	1·039	1·034	1·029	1·024	1·019	1·014
30·5	1·067	1·062	1·057	1·052	1·047	1·042	1·037	1·032	1·027	1·022	1·017
30·6	1·071	1·066	1·061	1·056	1·051	1·046	1·041	1·036	1·031	1·026	1·020
30·7	1·074	1·069	1·064	1·059	1·054	1·049	1·044	1·039	1·034	1·029	1·024
30·8	1·078	1·073	1·068	1·063	1·058	1·053	1·048	1·043	1·037	1·032	1·027
30·9	1·081	1·076	1·071	1·066	1·061	1·056	1·051	1·046	1·041	1·036	1·031
31·0	1·085	1·080	1·075	1·070	1·065	1·060	1·055	1·049	1·044	1·039	1·034

⁂ The numbers in the above table have been calculated from the formula $n = \frac{17·64 (h - a)}{460 + t}$, *a* the tension of aqueous vapour at *t*°. If *v* is any volume at *t*° and *h* inches

DIFFERENT TEMPERATURES AND UNDER DIFFERENT ATMOSPHERIC PRESSURES.

BAR.	THER. 62°	64°	66°	68°	70°	72°	74°	76°	78°	80°	82°	84°
28·0	·927	·922	·917	·912	·907	·902	·897	·892	·887	·881	·875	·870
28·1	·930	·926	·921	·916	·911	·905	·900	·895	·890	·884	·879	·873
28·2	·934	·929	·924	·919	·914	·909	·904	·898	·893	·887	·882	·876
28·3	·937	·932	·928	·922	·917	·912	·907	·902	·896	·891	·885	·880
28·4	·941	·936	·931	·926	·921	·915	·910	·905	·900	·894	·888	·883
28·5	·944	·939	·934	·929	·924	·919	·914	·908	·903	·897	·892	·886
28·6	·947	·943	·938	·932	·927	·922	·917	·912	·906	·901	·895	·889
28·7	·951	·946	·941	·936	·931	·925	·920	·915	·909	·904	·898	·893
28·8	·954	·949	·944	·939	·934	·929	·924	·918	·913	·907	·901	·896
28·9	·958	·953	·948	·942	·937	·932	·927	·921	·916	·910	·905	·899
29·0	·961	·956	·951	·946	·941	·935	·930	·925	·919	·914	·908	·903
29·1	·964	·959	·954	·949	·944	·939	·933	·928	·923	·917	·911	·906
29·2	·968	·963	·958	·952	·947	·942	·937	·931	·926	·920	·914	·909
29·3	·971	·966	·961	·956	·950	·945	·940	·935	·929	·923	·918	·912
29·4	·975	·969	·964	·959	·954	·949	·943	·938	·932	·927	·921	·915
29·5	·978	·973	·968	·962	·957	·952	·947	·941	·936	·930	·924	·919
29·6	·981	·976	·971	·966	·960	·955	·950	·944	·939	·933	·927	·922
29·7	·985	·980	·974	·969	·964	·959	·953	·948	·942	·937	·931	·925
29·8	·988	·983	·978	·972	·967	·962	·957	·951	·946	·940	·934	·928
29·9	·991	·986	·981	·976	·970	·965	·960	·954	·949	·943	·937	·932
30·0	·995	·990	·985	·979	·974	·968	·963	·958	·952	·946	·941	·935
30·1	·998	·993	·988	·983	·977	·972	·966	·961	·955	·950	·944	·938
30·2	1·002	·996	·991	·986	·980	·975	·970	·964	·959	·953	·947	·941
30·3	1·005	1·000	·995	·989	·984	·978	·973	·968	·962	·956	·950	·945
30·4	1·008	1·003	·998	·993	·987	·982	·976	·971	·965	·959	·954	·948
30·5	1·012	1·006	1·001	·996	·990	·985	·980	·974	·969	·963	·957	·951
30·6	1·015	1·010	1·005	·999	·994	·988	·983	·977	·972	·966	·960	·954
30·7	1·018	1·013	1·008	1·003	·997	·992	·986	·981	·975	·969	·963	·957
30·8	1·022	1·017	1·011	1·006	1·000	·995	·990	·984	·978	·972	·967	·961
30·9	1·025	1·020	1·015	1·009	1·004	·998	·993	·987	·982	·976	·970	·964
31·0	1·029	1·023	1·018	1·013	1·007	1·002	·996	·991	·985	·879	·973	·967

where *h* is the height of the barometer in inches, *t* the temperature on the Fahrenheit scale, and pressure, and V the corresponding volume at 60° and 30 inches pressure, $V = v\,n$.

description of candles to be used in their official testing stations during the winter 1894–95:—

"The candles to be used for testing the illuminating power of gas are defined by the Metropolitan Gas Acts as 'sperm candles of six to the pound, each burning 120 grains an hour.' Before being issued to the gas examiners the candles shall be sent to the office of the Gas Referees, by whom samples from each batch will be examined and tested.

"Packets of candles approved by the Gas Referees will be sealed by them, and certified for use in the testing places. No other candles than those which have thus been sealed and certified shall be used for gas testing.

"In order to diminish as far as possible the differences found to exist between different candles, it is desirable that the following regulations (including a previous examination of wicks by the Referees) should be adhered to, but for the present the Referees will examine any candles which may be submitted to them by the proper authorities, and will, if the candles on examination are found to be satisfactory, certify them for use in the testing places.

"**Regulations for Securing Uniformity in Standard Candles.**—1. The wicks shall be made of 3 strands of cotton plaited together, each strand consisting of 18 threads. The strands shall be plaited with such closeness, that when the wick is laid upon a rule and extended by a pull of about 1 ounce, just sufficient to straighten it, the number of plaits in 4 inches shall not exceed 34, nor fall short of 32.

"Each wick shall be of suitable length, not less than 12 inches, and looped ready for fixing in the mould. After having been bleached in the usual manner and thoroughly washed (see p. 239), the wicks shall be steeped in a liquid made by dissolving 1 ounce of sal ammoniac, and ½ ounce of crystallized boracic acid in a gallon of distilled water; they are then to be gently wrung or pressed till most of the liquid has been removed, and dried at a moderate heat while lying horizontally.

"Such a wick cut to a length of 12 inches, when stretched as above, shall weigh not more than 7 nor less than 6 grains. The weight of the ash remaining after the burning of 10 wicks which have not been steeped in boracic acid, or from which the boracic acid has been washed out, shall be not more than 0·03 grain.

"Wicks made in accordance with this prescription shall be sent to the office of the Gas Referees, by whom they will be examined and certified.

"The wicks so certified are to be used by the candle-maker in the condition in which they are returned to him.

"When the wicks are set in the mould, they should be pulled with only so much force as is necessary to straighten them.

"2. The spermaceti of which the candles are made shall be genuine spermaceti, extracted in the United Kingdon from crude sperm oil, the product of the Sperm Whale (*Physeter macrocephalus*). It shall be so refined as to have a melting point lying between 112° and 115° F. An account of the method by which the melting point of the spermaceti is to be determined is given on p. 239.

"Since candles made with spermaceti alone are brittle, and the cup which they form in burning has an uneven edge, it is necessary to add a small proportion of beeswax or paraffin to remedy these defects. The best air-bleached beeswax, melting at or about 144° F., and no other material, shall be used for this purpose, and the proportion of beeswax to spermaceti shall be not less than 3 per cent., nor more than 4½ per cent.

"3. The candles made with the materials above described shall each weigh, as nearly as may be, $\frac{1}{6}$ of a pound, and will be found to answer to the following test:—Immerse a candle taper-end downwards in water of 60° F., with a brass weight of 40 grains attached to the wick by a small piece of thread; when a further weight of 2 grains is laid on the butt end of the candle it will still float, but with a weight of 4 grains it will sink.

"The candles shall be sent to the office of the Gas Referees, by whom samples from each batch will be examined and tested. Each batch of candles shall be accompanied by a specimen of the spermaceti (unmixed with beeswax) which was used in making them.

"**Method of Washing Wicks.**—As it is found to conduce to the regular burning of candles that the wicks should have been as far as possible cleaned and freed from mineral matters, it is recommended that the candle-maker, before steeping the wicks, shall wash them first in distilled water made alkaline with between 1 and 2 per cent. of strong liquid ammonia, then soak them for several hours in dilute nitric acid containing about 10 per cent. of strong acid, and finally wash them in distilled water made alkaline with a few drops of ammonia.

"**Method of Determining the Melting Point of the Spermaceti.**—As various methods are used by different refiners of spermaceti for determining the melting point, which lead to different results, it must be noted that the temperatures here given as the limits within which the melting point of a sample of refined spermaceti should fall—viz., 112° and 115° F., have been found by the following method, which is known as the capillary-tube method:—

"A small portion of the spermaceti is placed in a short test-tube, and melted by plunging the lower end of the tube in hot water. A glass tube drawn out at one end into a capillary tube about 1 mm. in diameter is dipped narrow end downwards into the liquid spermaceti, so that, when the tube is withdrawn, 2 or 3 mm. of its length are filled with spermaceti, which immediately solidifies. The corresponding part of the exterior of the tube also becomes coated with spermaceti, which must be removed.

"The narrow part of the tube is then immersed in a large vessel of water at a temperature not exceeding 110° F. The lower end of the tube, which contains the spermaceti, should be 3 or 4 inches below the surface and close to the bulb of a thermometer. The upper end of the tube must be above the surface, and the interior of the tube must contain no water. The water is then slowly heated, being at the same time briskly stirred so that the temperature of the whole mass is as uniform as possible. When the plug of spermaceti in the tube melts, it will be forced up the tube by the pressure of the water. The temperature at the moment when this movement is observed is the melting point."

Even the precautions in manufacture and testing of the candles proposed here by the Referees do not make the candle a satisfactory standard, and the opinion of the Committee on Photometric Standards, appointed by the Board of Trade in December, 1891, is against the continued use of it in actual testing. The Committee state that the melting point of the so-called sperm varies unavoidably, and that the wick causes variations in the amount of light emitted. But they say, further, that there are more fundamental objections to the candle, and that it cannot be made a reliable standard. The light-giving value of a candle-flame is seriously affected by the way in which it is lighted, the length of time it has been burning, whether the cup of the candle is dry, or contains melted sperm, the roughness or smoothness of the wick, the curvature of the wick, the position of the wick towards the photometer disc, the rate of flow of air near the photometer, and the temperature of the air. Hence, it would be an unreliable standard of light, even if the most absolute uniformity could be ensured in its manufacture. Another point is the impossibility of making candles which will burn 120 grains per hour, or even within 5 per cent. of that amount. If candles were made officially with the greatest care and supervision, there would still remain variations in the amount of light given. The Board of Trade Committee concludes the portion of its report on the use of sperm candles thus:—"For these reasons, the sperm or any other candle, however manufactured, must be considered so untrustworthy that we unhesitatingly recommend its abolition as a standard of light, and the introduction of some more uniform and reliable unit." The report contains the evidence of Mr. G. T. Miller on the changes which have taken place in the manufacture of sperm candles since 1876, given before the Committee, and also much information on the wicks used since 1869. For further details on these heads the report of the Committee, issued as a departmental paper in 1895, should be consulted.

Those anxious to gather further information on the general use of candles as photometrical standards cannot do better than refer to a small book called *The Gas Analyst's Manual*, by F. W. Hartley.

Standard Lights.—Various standard lights have been proposed as substitutes for the standard candle, and as it is improbable that the latter will be retained for long as the official standard, some of these merit special notice here.

Pentane or Air-gas Lamp.—No experimenter has worked so indefatigably or so successfully at the production of a fit substitute for the standard candle as A. Vernon Harcourt, who has for many years been one of the Gas Referees for the Metropolis. There is a strong probability that his labours will very shortly gain their merit, in the adoption of his pentane lamp as the recognised official standard unit of light by the Board of Trade, such unit being the value of an average sperm candle as earlier defined. The adoption has been recommended by several influential committees, after exhaustive research, and especially by one which has just concluded its investigations. The subject of substitutes for the candle cannot, therefore, be better introduced than by a review of Harcourt's more recent labours.

At the meeting of the British Association in 1877, a paper was read before the Chemical Section by A. Vernon Harcourt, M.A., F.R.S., on "A New Unit of Light for Photometry." An abstract of this paper appears in the *Brit. Ass. Report* for 1877, *Trans. of the Sections*, p. 51, and runs as follows:—"After pointing out the variations to which the unit of light now in use—a sperm candle burning 120 grains of sperm per hour—is liable, and the irrelevance, for the purpose of estimating the value of illuminating gas, of tests affected by any other portions of the force radiating from a flame besides those which produce vision, the author explained the application of the new unit of light to the examination of coal gas. By making a mixture in a small gasholder of the most volatile spirit from American petroleum, which distilled at 50° C., with ordinary air, in the proportion of 1 of the liquid to 600 of air, or 7 of the vapour to 20 of air, he prepared a gas which was scarcely at all soluble in water, and was permanent at ordinary temperatures and pressures. This gas was burnt at a pair of burners, corresponding to the two candles commonly used in photometry, each consisting of a brass tube surmounted by a plate, through which the standard gas issued at the rate of half a cubic foot per hour through an opening $\frac{1}{4}$ of an inch across. The illuminating power of the gas and the rate of burning were so adjusted that each burner gave the average light of one candle. Photometric results obtained with the same sample of coal gas showed that successive observations made with standard gas gave closely corresponding results."

Four years after the presentation of the air-gas unit burner to the British Association Meeting, a Committee of the Board of Trade on Photometric Standards issued their report, dated August 25, 1881. In this report the Committee find that, compared with the sperm candle, Harcourt's air-gas flame is exact and trustworthy as a standard of light. The average illuminating power of a specially-stored sample of coal gas was determined alternately by means of the standard candles and by the air-gas flame. According to the sperm candles the average illuminating power was 15·99 candles, according to the air-gas flame 16·02 candles, during a period of a fortnight. Thus, the average value of the sperm candle was found to be practically identical with the light given by the air-gas flame. The Committee recommend that Harcourt's air-gas flame, as defined in the appendix to the report, should be employed in the determination of the illuminating power of coal gas. The portion of the appendix relating to Vernon Harcourt's standard air-gas flame is as follows :—

"The standard proposed by Mr. Vernon Harcourt, which has been adjusted to correspond to the light of a sperm candle consuming 120 grains of sperm per hour, has been described by him in a paper 'On a New Unit of Light for Photometry,' read at a meeting of the British Association in August, 1877, and in a letter addressed to the Board of Trade in April, 1879. The following extracts from these documents contain Mr. Harcourt's description :—'For the standard combustible I employ a mixture of air with that portion of American petroleum which, after repeated rectifications, distils at a temperature not exceeding 50° C. This liquid consists almost entirely of pentane, the fifth member of the series of paraffins. The proportion which I propose to maintain is 576 volumes of air to 1 volume of pentane, measuring the liquid at or near 60° F.; or, measuring both as gases—20 of air to 7 of pentane. In the burner proposed to be used with the standard gas, the opening has a diameter of ¼ inch. The length of the brass tube which the gas enters near its base is 4 inches, its diameter is 1 inch, and the thickness of the disc which forms the mouthpiece is ½ inch.'

"The height of the flame is accurately adjusted to 2½ inches. The specific gravity of the liquid, the volume of the gas yielded, and the rate of burning to produce a 2½-inch flame are defined by Mr. Vernon Harcourt in the following letter to ourselves :—The petroleum used is prepared by fractional distillation from the light American petroleum prepared by Messrs. Pratt & Co., of New York, and imported to this country in tins for the air gas companies. The specific gravity of the petroleum varies very slightly from 0·65. For purification, it is shaken up first with oil of vitriol, and then with a solution of caustic soda. The liquid decanted off is distilled four times backwards and forwards between two large flasks—at 60°, 55°, 50°, and again at 50° C.

"We have received the following letter from Mr. Vernon Harcourt relating to the adoption of the name 'air gas' instead of 'pentane,' and containing results of his latest experiments on the illuminating power of the different portions of 'standard' petroleum separated from one another by fractional distillation:—

"'To the COMMITTEE ON PHOTOMETRIC STANDARDS.

"'Gentlemen,—I send, at your request, a further account of the method of preparing the gas whose combustion furnishes the standard of light I have proposed.

"'The liquid used for its preparation is the lightest and most volatile portion of American petroleum, obtained by purifying and rectifying, in the manner already described, the "gasoline" or light petroleum, procured by the air gas companies in this country from Pratt, of New York. The rectified liquid begins to distil at about 65° F., and the distillation is almost complete when the temperature of the vapour has reached 120°. The liquid consists of hydrocarbons of the paraffin series, chiefly of pentane, but with an admixture of the homologous substances—tetrane and hexane. Its specific gravity varies between the limits 0·628 and 0·631 at 59° F., but recent experiments have shown that an air gas of the same illuminating power is obtained with samples varying in specific gravity between 0·614 and 0·645. The vapour of the liquid weighs two and a-half times as much as an equal volume of air.

"'By allowing a measured volume of this liquid to diffuse into, and mix with, a measured volume of air in the proportion of 3 cubic inches of the liquid to every cubic foot of air, under an atmospheric pressure of 30 inches of mercury, and at the temperature of 60° F., a standard air gas may be prepared in any required quantity. A gasholder of the size and form of that set up in the office of the Gas Referees is convenient for making and storing a quantity of the standard air gas sufficient for thirty testings. It consists of a cylindrical bell of about 7 cubic feet capacity, suspended and counterpoised in the usual manner over a tank having an annular space filled with water. A graduated scale attached to the bell serves to measure the volume of air drawn in, and also the volume of vapour formed from the measure of petroleum, which is poured through a tap into the holder. When 3 cubic feet of air and 9 cubic inches of light petroleum are used, the total volume of standard air gas formed is 4·05 cubic feet. The observation of this volume furnishes a check on the preparation of the standard air gas. Allowing a margin of 1 per cent. each way for small errors in making and measuring the gas, and for variations in the vapour density of the rectified petroleum, I would propose, in defining the standard air gas, to require that the volume produced from 3 cubic feet of air and 9 cubic inches of petroleum (specific gravity 0·628 to 0·631) shall not be less than 4·01, nor more than 4·09 cubic feet. The gas thus prepared is subjected to a further control by the requirement that its rate of burning from a $\frac{1}{4}$-inch orifice to produce a $2\frac{1}{2}$-inch flame must not be less than 0·48, nor more than 0·52 cubic foot per hour.

"'For the name of the liquid used to make the gas, I think it better to drop the unfamiliar word "pentane," and to call it "standard petroleum"—a name which suggests the fact that the liquid is obtained from petroleum by a special process of purification and rectification. The term "air gas" appears to have established itself as the name of a combustible gaseous mixture, made by saturating air with the vapour of hydrocarbons, and, therefore, I now propose to call the mixed gas, prepared as has been described, "standard air gas."

"'I enclose a statement of the results of a comparison made recently of standard air gas with samples prepared from petroleum distilled at various temperatures, ranging between 65° and 120° F.* The figures show how small an error would be caused by even considerable variations from the prescribed method of preparing standard petroleum, provided a sufficient purification and rectification have been made.

"'(Signed) A. VERNON HARCOURT.'"

Harcourt's Standard Lamp.—The favourable nature of the reports and comments on the pentane air-gas unit of light did not prevent the inventor taking steps in another direction with a view to producing a reliable standard of light, which should be more portable. He retained the use of pentane or standard petroleum, but constructed a lamp which should burn the vapour of the liquid direct from a reservoir. The gasholder and its appurtenances were thus dispensed with. The first pattern of lamp was not very successful, and it was superseded by a later design of Harcourt's which was presented by the inventor to

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* Illuminative value of air gas prepared with samples of petroleum rectified at different temperatures, that of the standard air gas rectified below 80° C. being taken as 100. Half a cubic foot of air, and $1\frac{1}{4}$ cubic inches of liquid petroleum were taken in each case.

Temperature, ° C.	Illuminative Value.
18° to 21°	101·3
21° ,, 24°	104·6
24° ,, 27°	102·2
27° ,, 30°	...
30° ,, 32°	100·3
32° ,, 33·3°	99·6
33·3° ,, 35·0°	101·6
35·0° ,, 36·3°	103·2
36·3° ,, 38·0°	101·9
38·0° ,, 40·0°	...
40·0° ,, 41·3°	101·1
41·3° ,, 46·0°	100·0
46·0° ,, 50·0°	98·1

the meeting of the British Association at Manchester in 1887, and described to the physical section of that body in a paper entitled "On a Standard Lamp."

The following is the substance of the abstract of the paper in the published report for the year:*—A lamp devised by Mr. Harcourt for producing a constant amount of light was exhibited at the meeting of the preceding year; the present one is simpler in principle, more easily adjusted, and less affected by draughts. It consists of a glass reservoir, with tubulure and stopper, of the form and size of a large spirit lamp, mounted on a metal stand provided with levelling screws. The wick can be turned up and down in the usual manner within a long tube attached to the body of the lamp. Round this tube is a wider tube 100 × 25 mm.; and the two being joined together above and below by flat plates constitute the burner of the lamp. When the burner becomes warm by conduction of heat from the flame the pentane which rises in the wick volatilizes, and the vapour burns at a considerable distance above the point to which the wick is turned down. Thus the size or texture or quality of the wick does not affect the flame. Around the burner and the lower part of the flame is another cylinder open at both ends and contracted above the burner to a tube 20 mm. in diameter and in length. A similar tube forms the lower part of an upper chimney which is enlarged above to a diameter of 25 mm. The upper part of the flame is concealed by this chimney excepting where a narrow slot 10 × 3 mm. on each side shows the tip of the flame, and enables its height to be regulated. Through the interval between the two chimneys the flame shines, and the light which it gives is the same whenever the tip of the flame is visible opposite the slot, whether towards the lower or the upper end. The two chimneys are attached together by two curved metal bands sufficiently removed from the flame on either side not to affect it. The attachment of these bands to the lower chimney is adjustable, so that the opening through which the central parts of the flame are seen may be made larger or smaller. By means of small cylindrical blocks whose thickness has been accurately gauged, the width of the opening may be set either to that at which the light emitted is one candle, or if a greater or smaller light is desired, a candle and a-half, or half a candle. The width of the connecting bands is half that of the tube which surrounds the flame. When these bands are placed in a plane perpendicular to the bar of a photometer, a point midway between their edges and at half the height of the flame may be taken very approximately as that from which the light radiates. The liquid with which the lamp is fed is pentane, obtained in a manner already described from American petroleum.

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* *Brit. Assoc. Reports*, 1887, p. 617.

British Association Report on Standards of Light.—At the next year's meeting of the Association a Committee, which had been engaged for four years in investigating proposed standards of light, presented their final report. The chief conclusions arrived at by the Committee are abstracted briefly from the "Report of the Committee of the British Association appointed for the purpose of reporting on Standards of Light" (*Brit. Ass. Reports*, 1888, p. 39).

The present standard candle is not worthy of being called a standard. The pentane standard of Mr. Vernon Harcourt is reliable and convenient, and fulfils all the conditions required in the adoption of a standard of light. This standard attains this end by its having no wick, and consuming a material of definite chemical composition. The experiments of the Committee also show that the light was not altered when the specific gravity of the pentane was 0·632 or 0·628, instead of the specified value of 0·630. Out of 118 tests on four standards, candles gave 87 tests differing by 1 per cent. from the day's average, 57 differed by 2 per cent., and 19 by 5 per cent. Variations of 9 and 10 per cent. occurred occasionally. Of the other three standards, the amyl-acetate lamp showed a variation of 2 per cent. from the day's average on four occasions out of the 118 tests, and a variation of 1 per cent. on eleven occasions. The pentane lamp twice only showed a variation of 1 per cent., the pentane standard once only. The pentane standard and the pentane lamp gave practically the same light.

The amyl-acetate lamp, mentioned in the above report, will be described later. It will be observed that Harcourt's pentane standard again triumphed after a most exhaustive trial, and that the pentane lamp of the same gentleman was found to be little inferior to it. The Committee appointed by the Board of Trade, which concluded its labours in 1894, also recommended the adoption of Harcourt's pentane standard as the unit of light for gas testing, and likewise found that it accurately represented the average light afforded by the standard sperm candle. A digest of the report of this Committee, issued in 1895, is given on p. 255. It would seem, therefore, that the time is really ripe for the official recognition of the Board of Trade to be extended to the pentane standard.

Harcourt's 10-Candle Standard Lamp.—It may be well here to allude to Harcourt's latest efforts, which have been directed towards the construction of a working standard, which shall emit a light of ten times the value of the standard candle. The outcome of his efforts was described in a paper read before the Physical section of the British Association at its 1894 Meeting. The paper will be found on p. 419, vol. lxiv., of the *Journal of Gas Lighting.* Its author states the advantages of a greater light than one candle for gas testing, and alludes to the use of air carburetted with pentane for the production of a uniform light of the value of ten candles. This light is described on p. 258.

With regard to the principle involved in its construction Harcourt says: — "The admixture of air is, however, unnecessary, since at a moderate temperature pentane can be volatilized without there being any necessity for reducing the atmospheric pressure by the admixture of another gas." Taking advantage of the fact thus clearly stated, Harcourt proceeded to construct a lamp which should directly burn volatilized pentane, and be capable of affording a constant light of ten candles. It will be observed that the principle embodied is that involved in the construction of the 1-candle pentane lamp. The burner is an Argand furnished with a wick to convey the pentane to the region where the heat of the flame conducted downwards is sufficient to volatilize it. The vapour burns from the open end of the annular space; the wick does not, therefore, come near the flame, and neither affects nor is affected by it. The air supply to the inner tube is steadied and regulated by passing through a chamber near the base of the tube. The light is brought to the colour of a gas light from a good burner by the indraught of air through 12 small holes in the outer tube at a distance of 15 mm. from its top. The dimensions of the lamp and chimney have been empirically determined to induce air currents that shall give a bright and steady flame. The chimney is surrounded by a cylindrical screen, and this by a five-sided shade, four sides of which are of blue glass. The fifth side is provided with a metal screen coming below the inner cylindrical screen, and this outer screen is fixed at such a height that the light escaping on that side below it has in the photometer a value of ten candles. The exact adjustment of the height of the circular screen, so that the light escaping below it may have this value, is obtained by making a large number of comparisons between it and a 1-candle standard. As will be explained later, the light thus emitted from the lower part of the flame does not alter appreciably, though the height of the flame itself varies considerably. Therefore the adjustment of the height of the flame need not be made with any great exactitude. Sundry simple precautions have to be taken in using the lamp in the photometer, but it possesses the immense advantage over other standards of ten or more candles of being readily portable. It is of too recent introduction to have been tried thoroughly by photometrists generally, but the reputation of the inventor is a sufficient guarantee of a standard proposed by him being sufficiently exact for the ordinary requirements of gas testing.

The Amyl-Acetate Lamp.—Very similar to the pentane lamp in principle is the amyl-acetate lamp already alluded to. This lamp is the invention of F. von Hefner-Alteneck, and was first designed in 1883. It has been somewhat modified since; a description of it by the author is given in the *Journal für Gasbeleuchtung* (vol. xxx., p. 489, as well as in other volumes) in 1887. The combustible is amyl acetate, which is an article of commerce, and can be readily obtained in a pure state. It is prepared by distilling amyl alcohol with sodium acetate and sulphuric acid, the first portion of the distillate being rejected. Pure amyl acetate boils at 138° C. The wick of the lamp passes up a circular tube of German silver, 8·0 mm. in internal, and 8·3 mm. in external diameter, and 25 mm. in height. The flame produced by the burning of the vapour of the amyl acetate is regulated to a height of 40 mm. from the top of the tube to produce the normal Héfner-Alteneck light. The height of the flame is to be measured after the lamp has been lighted for at least ten minutes. The wick should be of a thickness to comfortably fill the tube; it is made up of a number of loose strands, the upper ends of which are cut level, and the lower ends all dip into the liquid. Further than this, the condition of the wick is of small moment, and does not materially affect the flame. Asbestos-capped wicks have occasionally been used, but appear to present no sufficient advantage. In general design, the lamp is of very ordinary construction. The eyes of the operator, when regulating the height of the flame, are protected from the glare from the lower portion of it by means of a screen. As the lamp was originally constructed, the flame was naked, and it was necessary that it should be in a perfectly pure and still atmosphere. It is often necessary to use a glass chimney to protect the flame from draughts, and on adjusting the flame to the normal height after the imposition of the chimney, the light emitted will be very slightly below the normal. Each chimney has its own constant in this respect, and this should be determined empirically. The light of the normal Hefner-Alteneck lamp was designed to be that of one normal candle, but it is in reality considerably less. According to the recent reliable determination published by Professor von Helmholtz for the German State Physical and Technical Institution, the light of the Hefner lamp under normal conditions is equal to 0·877 English standard sperm candle, or one English sperm candle is equal to 1·14 Hefner unit of light. The Institution undertakes the standardizing of the lamps at Charlottenburg, the extreme variation allowed being 2 per cent. The flame of the Hefner-Alteneck lamp is unfortunately redder in tint than the flame of a standard candle, and very much redder than that of gas burnt at a good burner. The exact comparison of the illumination from two sources of light of differing tints is a physiological, if not a physical, impossibility, and, consequently, the Hefner light is an unsatisfactory standard for gas testing. The redness of the flame is intensified on raising it above the normal height, as has been done in attempting to get a light exactly equal to that of one candle from the lamp. Nevertheless, even under these conditions, the Committee of the British Association (1888) found that the lamp showed only four variations of over 2 per cent., and eleven of over 1 per cent. from the day's average among a total of 118 tests (see p. 246). This proves the lamp to be immeasurably superior to candles as ordinarily used in photometry, but inferior to the pentane standard. The lamp is, however, very largely used in Germany, and has to a considerable extent superseded the German standard paraffin candle. The red colour is less marked when the flame is at the normal height, and the amyl acetate consumed is pure, and the observance of these conditions perhaps accounts for the greater success it has had in Germany than in trials in this country, where even so-called experienced photometrists have proceeded to test its accuracy by using the lamp in a manner never purposed by the inventor.

The Methven Screen.—The proposed substitute for candles as a standard of light which may be regarded as ranking next to the Pentane standards of Harcourt in importance is the Methven screen, modified forms of which are now largely used where officialdom does not stipulate for the use of candles. The original form of the screen appeared about 1878, and was the invention of John Methven. The standard light was obtained by burning ordinary coal gas in a Sugg's "London" Argand burner, the flame being regulated to a height of 3 inches. A portion of the light from this source was allowed to pass through a slot in a vertical silver screen to the photometer disc. Methven had observed that when the light from the edges of a flame was intercepted by a screen a short distance from the flame, the light from the central portion had an all but constant value, notwithstanding slight variations in the height of the flame. Taking advantage of this observation, he empirically found the dimensions of a slot which should allow light equivalent to that from two standard candles to pass through it, when the vertical plate in which the slot existed was placed at a fixed distance from a standard "London" Argand burner, consuming coal gas, the lower border of the slot being at a definite height in respect to the burner. This standard, as originally made, was found wanting in accuracy by the Committee of the Board of Trade, which issued its report in 1881. It appeared that the amount of light passing through the slot varied somewhat with the quality of the coal gas consumed, and hence it was considered that an error would be caused on testing gas by means of the same gas burnt behind a Methven screen as the standard light. In a communication to the meeting of the Gas Institute in June, 1882, Methven described a modified form of his standard. This consisted of a standard Argand burner consuming coal gas enriched by the vapour of "carburine" or "pentane." A screen allowing only the light from a small portion of the flame to pass through was used, as in the earlier invention. The richer gas required two alterations on the earlier form to be made. The flame of the standard Argand used was regulated to a height of 2½ instead of 3 inches, and the dimensions of the slot were altered to suit the shorter and more luminous flame. The slot was shortened, but, at the same time widened, the dimensions for carburetted gas, given by Methven in the paper above referred to, being about 15 mm. high and 8 mm. wide. The light was to be taken from a portion of the flame (of carburetted coal gas) 24 mm. above the burner. Heisch and Hartley issued, in 1883, a very favourable report on the Methven screen as a method of obtaining a convenient standard light. To obtain the best results from the Methven screen, the size of the slot must be carefully adjusted to suit the particular chimney to be used on the Argand burner, and it is even a safe precaution to standardize the slot for one portion of the chimney, and to mark the latter so that that same portion can always be placed before the slot. If this precaution is taken the standard is free from error on the score of varying thickness or refractive index of the glass of the chimney. The height of the flame should not deviate greatly from the normal. The standard is most satisfactory in an open photometer. The carburettor, which must be perfectly air-tight, consists of a metal box with inlet and outlet pipes, both provided with taps. There is also a bye-pass between the inlet and outlet pipes, likewise furnished with a tap, so that the gas can be supplied to the burner of the standard either carburetted or uncarburetted. This arrangement is especially useful when the standard is in use at very frequent intervals, as the supply of pentane or carburine can be cut off without extinguishing the gas flame, facilitating the economizing of the hydrocarbon, which, if specially fractionated (as "pentane"), is, in this country, a somewhat expensive product. This form of carburettor is used for other standard lights, which are supplied with carburetted air or gas.

Dibdin's 10-Candle Standard.—Very similar in principle to the Methven standard is that proposed by W. J. Dibdin. This is a carburetted gas-flame standard, designed to give a light equal to that of ten standard candles. The light from the top of the flame only is cut off, it having been observed that that from the remainder of the flame remains constant, even under considerable changes in height of the flame itself. A small Argand burner is used, the height of flame being kept approximately at 3 inches, indicating bars being provided to facilitate its regulation. Air under pressure is passed over pentane in a carburettor, and forms the gas consumed, or ordinary coal gas carburetted with pentane may be used instead. The lower edge of the screen is about 2·3 inches above the top of the burner, but, of course, each standard should be carefully standardized, and the screen adjusted to the exact height that gives the illuminating power of ten candles to the exposed part of the flame. Considerable variations in the height of the flame leave the value of the standard unaffected, but the height should be as nearly as possible 3 inches. This standard is trustworthy, and very convenient for gas testing, and is also applicable to other photometrical uses. The inventor states that the value of the standard is independent of the temperature of the carburettor, at least between 0° and 32° C., provided the flame is adjusted to the normal height.

The Dibdin 10-candle Argand pentane-air flame standard has been thoroughly tested by the Committee of the Board of Trade appointed in 1891. In the report of this Committee issued in 1895, of which a digest is given on p. 255, the use of this standard is recommended in the testing stations of the Metropolis, as there are many practical advantages in the use of a standard light of approximately equal value to that of the gas flame under observation. Further details of the construction and method of using this simple standard may be gleaned from the above report, and the abstract of the appendix to the same given on p. 257. There is every prospect of this standard shortly receiving official recognition for practical use; while Harcourt's pentane unit is retained as the absolute standard representing the statutory sperm candle. The Dibdin 10-candle burners and screens would then be standardized against the Harcourt pentane unit.

Sugg & Co.'s 16-Candle Standard.—Wm. Sugg & Co. also supply a 16-candle standard, similar in principle, but not quite so reliable as Dibdin's 10-candle standard. Wm. Sugg has devised a 10-candle standard in which the upper part of the 3-inch flame of an Argand burner consuming ordinary gas is cut off. The burner is mounted on a meter through which the gas for its supply passes, and by which the rate of consumption can therefore be ascertained. Correction is made for the rate of consumption by means of a table compiled by the inventor of the standard. The height of flame visible below the screen is about 1¾ inches.

The Dutch Committee's Standard Lamp and Burner.—A new standard lamp, which in some respects resembles the pentane and amyl-acetate lamps, has been produced by the committee appointed by the Association of Gas Managers of Holland. This committee only presented its final report and recommendations in 1894, so there has been but little opportunity as yet of their lamp being tried by others. The fuel of the lamp is a mixture of 9 parts by weight of benzene with 100 parts by weight of ether. The lamp has a cylindrical wick, which merely serves to convey the fluid at the required rate to the points of vaporization in the tube, at the top of which the vapour burns. The chimney is a cylindrical metal one, having two rectangular openings facing one another, through which the flame is visible. The lamp is suspended during use, so that it always hangs vertically. The value of the light emitted by this lamp was found to be equal to 1·48 English candles. The light appeared to be of very constant value; two of the lamps tried against one another showed, on a large series of tests, a mean deviation from the average value of only ± 0·62 per cent. It does not pretend to greater constancy than the pentane lamp, but the fuel is cheaper and more readily obtained in all parts of the world. The same committee of Dutchmen also recommended a system of gas testing based on the relative variations in the lighting power of two different zones of a rat-tail flame with varying qualities of gas. The most sensitive portion of such a flame to different qualities of gas, is that which lies between the heights of the dark cone of the flame, with the most divergent qualities of gas consumed in it, the rate of consumption being varied to give a constant height of flame. By screening off all the flame but the zone so indicated, the standard burner of the Dutch Committee, sensitive to very slight changes in the quality of the gas, is obtained. A less sensitive zone, and one, indeed, the lighting power of which varies almost imperceptibly with the quality of the gas, is that above the highest point at which the dark cone of a flame of constant length ever appears with the qualities of gas likely to be consumed in it. The relative value of the light issuing from this zone of a flame, and from the above standard burner consuming the same gas, varies with the quality of the gas, and serves as a measure of that quality. The absolute illuminating power of the gas is found by a reference to a table based on carefully-made observations with gas of known lighting value. A new and simple system of photometry, as applied to gas, has thus been devised by the Dutch Committee, and awaits further investigation. It may be pointed out that in the method of observation they prefer, a constant distance is preserved between the disc and the standard light. A tolerably full abstract of their report will be found in the *Journal of Gas Lighting*, vol. lxiv., pp. 1161 and 1209; for further information, the original report, published at Leiden by P. W. M. Trap, should be consulted.

It is unlikely that any standard of light other than some one of those mentioned above will be adopted either as an official standard or for rapid working in gas testing in this country. There are, however, a few more standards of light of some interest, which are briefly mentioned below.

The German Standard Paraffin Candle.—Akin to the English standard sperm candle is the German standard paraffin candle, which, however, is largely superseded in that country by the Hefner-Alteneck lamp, especially for research purposes. These candles are sold in half kilogramme packets, each packet containing 10 candles. They are prepared of purified paraffin, to which a small percentage of stearine is added. The melting point of the paraffin, the number of strands in the wick, and the weight of the latter, as well as the height of the flame in testing, are carefully defined, but the attempt to make a reliable standard appears to have failed notwithstanding these elaborate precautions. The German candle has a slightly higher lighting value than the English sperm candle; a recent investigation shows that with a height of flame of 45 mm. 1 German standard paraffin candle is equivalent to 1·05 English standard sperm candle.

Carcel Lamp.—The standard of light in France is the Carcel lamp, a simple wick lamp consuming refined colza oil. The burner is on the Argand principle, a wick weighing 3 grammes per decimetre being used in the annular space, from which it should protrude 10 mm. The dimensions of the burner and glass chimney are precisely defined, and the chimney is placed on the lamp so that the shoulder is 7 mm. above the top of the wick. The lamp should normally burn 42 grammes of oil per hour, but if the consumption falls between 38 and 46 grammes of oil per hour, correction is made for the deficiency or surplus, on the assumption that 42 grammes of oil are equivalent to one Carcel unit of light. The range allowed is too large, and near the extreme limits, the assumption is not justified. For slight variations, say for a consumption of 40 to 44 grammes of oil, the correction is permissible. The wick must be renewed, and the lamp allowed to burn for half an hour before each testing. The value of the "Carcel" unit of light is, according to recent researches, exactly 10 English standard sperm candles; values obtained by early investigators ranged from 9·4 to 10·0.

Keate's Lamp.—Similar to the Carcel lamp was the Keate's lamp, a 10-candle standard from the consumption of sperm oil. This was subsequently converted into a 16-candle lamp, and numerous attempts were made to obtain its recognition as a standard in this country. The difficulty of maintaining a steady flame of uniform lighting power by the consumption of oil from wick is too great to place the Carcel and Keate's lamps in the category of reliable standards. The need of ascertaining the consumption of oil by weighing is a great bar to their adoption.

Violle's Standard Light.—The attention of the Committee of the British Association had been directed to a standard proposed by M. Violle, and they reported in 1888 (see *Brit. Ass. Reports*, 1888, p. 45) on this standard to the following effect. The standard is the light emitted by a square centimetre of liquid platinum at the solidifying point. The apparatus required for the production of such a standard is of necessity very cumbrous and inconvenient, and extremely ill-suited for photometrical measurements. An endeavour was made to find methods of obtaining the same result in a more convenient manner and on a smaller scale, with the view of constructing apparatus which could, without inconvenience, be introduced into an ordinary photometer. The light from platinum foil heated to its point of fusion by means of an oxyhydrogen jet, and also by means of the electric current, was examined through a $\frac{1}{4}$-inch circular aperture in a steatite plate, but the photometrical results showed that no reliance could be placed on them. The surface of molten platinum was found to have small scum-like particles constantly floating over it, and these particles gave far more light than the mass of metal itself. As there existed no means of ensuring the absence of such particles, it was obvious that there could be little certainty in the light emitted from such unevenly illuminated surfaces. In all the experiments it appeared that the amount of radiation from a given surface of platinum at the moment of fusion is not absolutely constant under the conditions mentioned. This *résumé* of the Committee's report will suffice to condemn, for ordinary use at least, the deliciously unpractical standard proposed by M. Violle. It will also serve to warn against platinum standards unless they are supported by stronger evidence of reliability than those hitherto presented. Some yet more fanciful schemes for standards of light may be here ignored.

REPORT OF THE BOARD OF TRADE COMMITTEE ON PHOTOMETRIC STANDARDS.

The following is the text of the report presented by the Committee (constituted on 23rd December, 1891) to the President of the Board of Trade in March, 1895. Annexed are brief abstracts of some sections of the appendix to the same:—

"1. It was intimated to us, by a letter from the Secretary to the Board, that the method at present in use for measuring the illuminative value of coal gas has been objected to, alike by the Metropolitan Gas Referees and the London County Council, as being of an unsatisfactory nature; that the London Gas Companies are alive to the defects in the present system; and that legislation is admittedly necessary for the purpose of substituting a more reliable standard for that now in existence; but that, in view of the difference in opinion as to what the substituted standard should be, the President of the Board deemed it advisable that, before his support was given to any legislation, the whole question should be considered by a Committee that would command the confidence of the various interests affected.

"2. The method at present in use for measuring the illuminative value of coal gas consists in comparing the light of the gas, when burning from a particular burner at a specified rate, with the light of a sperm candle burning also at a specified rate, which last is taken as a standard. We have satisfied ourselves, from considerations set forth in the appendix to this report (see p. 239), that the flame of a sperm candle does not furnish a satisfactory standard, by reason of the amount of light which it affords varying over a wide range, under conditions as to the manufacture of the candle, as to its mode of use, and as to adventitious circumstances attending its use, which, as a whole, it is not possible to regulate and define.

"3. Though recognising, however, that the sperm candle flame does not furnish a satisfactory standard, we nevertheless consider it advisable that, in official documents and reports, the quantity of light yielded by coal gas burned under specified conditions should continue to be expressed as heretofore, in terms of candle light, the actual comparison, however, being made between the gas light and some well-defined and constant light ascertained to be equal in quantity to, or a definite multiple of, the average light given by the standard sperm candle.

"4. We have further come to the conclusion that, in the present state of experience and knowledge, the source of the light to be used as a standard by gas testers generally must be produced by the process of combustion, and be in the nature of a flame.

"5. We find that the 1-candle light flame proposed by Mr. A. Vernon

Harcourt as giving a standard light, and commonly known as the 'Harcourt pentane air-gas flame,' when used under the conditions defined, does constitute a very exact standard, capable of being reproduced at any time without variation of illuminative value.

"6. We have satisfied ourselves that the light given by Mr. Harcourt's above-mentioned pentane air-gas flame as defined, in respect to the conditions of its production, in the Appendix (Section III.) is a true representative of the average light furnished by the sperm candle flame constituting the present standard. Since 1879, when the pentane air-gas flame was first introduced, many series of experiments have been made by different observers, in which the light of the proposed standard has been compared with the light of the standard sperm candle flame, with the result that in those series of experiments in which the height of the pentane air-gas flame was adjusted strictly according to the directions given in the Appendix, the light afforded by this flame was found to agree exactly with the mean result afforded by the standard candle flame. In other series of experiments, indeed, in which a slight variation was made in the mode of adjusting the height of the pentane air-gas flame, some discrepancies in the direct results furnished by the comparison of its light with that of the standard candle flame were observed; but in these several series of experiments also, when the necessary correction, called for by the difference in the mode of adjustment resorted to, was made, the light of the pentane air-gas flame was found to accord closely with the mean result afforded by the standard candle flame.

"7. Inasmuch, however, as there is a practical advantage in comparing directly the light of such a coal-gas flame as is usually tested (being, that is, of about a 16-candle light value), with a light approximating somewhat in value thereto, we have further submitted to careful examination the flame of the 10-candle light pentane Argand proposed as a standard by Mr. W. J. Dibdin in 1886. This flame is produced by burning a mixture of air and pentane vapour from a suitable Argand burner, provided with an opaque screen by which the light from the upper portion of the flame is cut off. The screen being set at a definite height, it was found by Mr. Dibdin that, owing to a compensating action affecting the lower or exposed portion of the flame, the luminosity of this portion of the flame remains constant even under considerable variations, whether in the total height of the flame or in the proportion of pentane vapour to air in the mixture burnt. With a view to simplify the construction of the Argand burner furnishing a cut-off flame of this constant luminosity, we have tried various changes in the form of the cone and in the division of the air supply to the flame, but in every case have found the original burner, as supplied by Mr. Sugg for the purpose, to give more satisfactory results than the modified forms.

"8. The amount of light emitted by the portion of the Dibdin Argand pentane-air flame that is used in photometry, being dependent on the distance above the steatite ring of a screen by which the upper part of the flame is cut off, we have come to the conclusion that when the bottom of the screen is fixed at a height of 2·15 inches (54·6 mm.) above the top of the steatite ring, the amount of light emitted by the lower portion of the flame is substantially equal to ten times the average light of a standard sperm candle flame, or to ten times the light of Mr. Harcourt's 1-candle light pentane air-gas flame.

"9. We have further satisfied ourselves that any number of Dibdin Argand burners may be produced, having the form and dimensions set forth in the Appendix (Section IX.); and that these several burners, when used in the manner there defined, may be depended on to furnish a flame giving, when duly screened at the top, ten times the average amount of light given by a standard sperm candle.

"10. We therefore recommend that the pentane-air flame furnished by a Dibdin Argand burner, having the form and dimensions set forth in the Appendix (Section IX.), and used in the manner there defined, be accepted as giving the light of 10 standard candles, and that this flame be authorized and prescribed for official use in testing the illuminating power of the gas supplied by the London Gas Companies.

"11. We further recommend that sealed specimens of the burner, the carburettor, and the pentane for use therewith, duly certified by the Gas Referees, be deposited with the Board of Trade, and also in such places and in the care of such persons as the Board may direct, to be available for the purpose of comparison, in the event of any question arising as to whether the pentane-air flame of some particular burner does or does not afford the same amount of light as that now proposed for adoption as a standard.

"12. With a view to making some provision for future possible improvements and requirements, we further recommend that the Gas Referees be authorized, should they at any time see fit, to approve and certify for use in gas-testing any other flame based upon the 10-candle standard defined above, which they may consider suitable for the purpose, whether produced in a like or unlike way, and whether having the same or a different multiple value; such other flame, however, not to be used for gas-testing unless approved by the Board of Trade, and unless the Gas Companies give their consent to its adoption as a standard.

"13. We further recommend that the illuminating power of coal gas shall continue to be recorded as heretofore in terms of the light given by a specified number of cubic feet (to wit, 5 cubic feet) burnt per hour from the standard London Argand burner, but that, in testing the illuminating power of the gas, the requirement that the gas shall actually be consumed at this rate be rescinded, so as to allow the Gas Referees to sanction a mode of testing in which the gas shall be burned from the Standard London Argand burner at whatever rate is found requisite, in order that it may give a light equal to that of the prescribed number of candles, and in which the illuminative value of the gas shall be calculated as being inversely as the rate at which such gas had to be burned during the testing so as to give this amount of light."

Appendix to the Report.

The first section of the appendix relates to the constitution of the Committee. The second section is on the use of sperm candles as a standard of light, and has been referred to on p. 239. The third section is a description of "Mr. A. Vernon Harcourt's 1-candle pentane air-gas unit." The description is substantially that given on p. 242. The fourth section deals with pre-existing evidence of the relative value of the light of a standard candle and of the 1-candle pentane air-gas flame. The bulk of this evidence has already been given in connection with the description of the standard (see pp. 241 and 246). The Committee come to the conclusion that the variations in the observations by different observers are due to variations in the way in which the flame of the 1-candle unit had been set to the prescribed height, and the fifth section is devoted to reporting the effect on the amount of light emitted of setting the height of the flame with and without a screen. The inventor of the 1-candle pentane flame has invariably set the flame with the luminous portion thereof screened from view, and if set in this manner it correctly represents the average light of 1-standard candle. The sixth section gives corrected tables of comparisons, which confirm the last conclusion. The seventh section is on the 10-candle pentane Argand, briefly described on p. 251, and recommended for use by the Committee. It gives the results of a long series of observations tending to prove that, whether air or coal gas was the carrier of the pentane vapour, the 10-candle standard gave practically uniform results, with a flame burning between the limits of 2½ and 4½ inches in height. Experiments on the influence of the depth of pentane in the carburettor on the light emitted by the 10-candle standard showed that so long as the bottom of the carburettor was covered there were no variations, and they proved also that atmospheric air could be used, instead of coal gas, as the carrying medium. Variations in the temperature of the carburettor, when sufficiently full of pentane, did not affect the value of the flame. As the result of trials of various chimneys, it was concluded that "care must be taken in the selection and centering of the chimneys, and that failing this, a slight error, perhaps of 2 or 3 per cent., is possible." From other trials, "it seems probable that the value of the standard is not materially affected by such variations of atmospheric pressure as commonly occur." The eighth section discusses the possibility of simplifying the Dibdin 10-candle pentane Argand, and also treats of the height at which the flame should be screened off, in order to emit a constant light of 10-candles. Only one slight modification of the original burner—viz., the substitution of a rectilinear for a curvilinear solid cone, was found an improvement, and the height above the steatite at which the screen must be fixed was found to be 2·15 inches. The ninth section describes the standard as recommended by the Committee for use in gas testing as follows:—

"**Dibdin's 10-Candle Pentane Argand Air-Gas Standard.**—The burner is a specially constructed tri-current Argand burner, the annular steatite ring being perforated with 42 holes, each hole being 0·71 millimetre in diameter. The three air currents are:—(1) The central current rising inside the steatite to the inner portion of the flame; (2) a current rising outside the steatite, and caused to impinge upon the flame by an inner metal perforated and incurved cone, the top of which is level with the top of the steatite; (3) an outer current rising on the outside of the above cone, and between that cone and the glass chimney.

"The inner perforated cone is punctured with 10 apertures 0·25 inch in diameter, which are provided for the purpose of equalizing the two outer currents of air as may be required to suit the height of the flame. The glass chimney is carried in the groove provided on the outer cone, which answers the purpose of a gallery; the dimensions of the chimney being 6 inches high and 1½ inches inside diameter. The top of the flame should be maintained as nearly as possible at 3 inches above the steatite; this point being indicated by the wires crossing the blue-glass screens carried on each side of the burner on the metal supports. The flame is steadied by the small air-directing cone situated centrally beneath the steatite; the apex being 0·03 inch below the metal support carrying the steatite.

"On the side of the burner to be presented to the photometer disc, a metal screen, 8½ inches in height, is placed and screwed securely to the base-plate. The middle portion of this screen is cut away so as to leave above the top of the steatite burner an opening 2·15 inches in height and 1·4 inches in width; the lower portion of this opening being exactly level with the top of the steatite. The light emitted horizontally through this opening by the flame produced by the combustion of the gaseous mixture of atmospheric air and pentane formed in the carburettor, described below, is used as the standard light. It is equal to the light emitted by 10 parliamentary sperm candles.

"The lower portion of the screen has an opening 1 inch wide by 2·3 inches in height, to allow free access of air to the under portion of the burner.

"The various dimensions and arrangements of the parts are more particularly described in the following table of measurements and accompanying detailed plans.

"The position of the burner in relation to the photometer disc is to be fixed by the burner fitting gas-tight into a faced joint attached to the photometer at the required point; and the burner is to be set at such a height that the centre of the illuminated disc and the bottom edge of the cut-off shall be in the same horizontal plane. The length of the connection between the burner and the carburettor may be varied, but should not be more than 5 feet.

"The centre of the flame is to be immediately over the terminal point of the photometer bar.

"The carburettor for the 10-candle pentane Argand consists of a circular vessel constructed of tinned plate—

Diameter, ...	203·2 mm.	= 8 inches
Depth, ...	50·8 ,,	= 2 ,,

having a spiral division 25·4 mm. = 1 inch in width. This division is made by soldering in a spiral strip of metal 4 feet 6 inches in length and 2 inches wide, gas-tight, to the under side of the top of the carburettor, so that when the top is fixed on, the bottom of the strip comes close to the bottom of the vessel and is sealed by the pentane, so that the air has to pass over pentane for a distance of about 4 feet 6 inches, and becomes thoroughly saturated.

"At the end of the spiral division, near the side of the carburettor, a bird fountain is fixed for charging the carburettor, and keeping it charged at a constant level with liquid pentane.

"The lower end of the inlet fountain tube is closed, and rests upon the bottom of the tank.

"Through the side of the tube, which is $\frac{4}{10}$ of an inch (10·1 mm.) in diameter, 16 holes 1 mm. in diameter are bored close to the bottom, and through these the pentane enters the carburettor. At one side of the inlet-tube, and 1 inch from the lower end, a small tube 33 mm. in diameter, and 20 mm. in length, is connected thereto and turned upwards. The fountain inlet-tube is carried up through the top of the carburettor, and continued in the form of a bulb having a capacity of about 200 c.c. Stop-cocks are provided at the top and bottom of the bulb for convenience in filling with pentane, and the portion above the upper stop-cock is opened out in a funnel shape for the same purpose. When the carburettor is being charged, the gas must be extinguished to avoid the risk of the vapour firing and causing an explosion.

"The inlet for gas or air is at the side of the carburettor, and at one terminal of the spiral division, the outlet being placed in the centre of the vessel, so that the air or gas may travel over the liquid pentane throughout the whole length of the spiral division, and thus become fully charged with the volatile vapour of the pentane.

"When using this standard, the pentane must be visible in the fountain bulb."

The tenth section of the Appendix relates to the effect of the humidity of the atmosphere upon the amount of light emitted by luminous flames. The Committee conclude that in a well ventilated testing room, with the temperature kept within a narrow range, no great differences are to be found in the light emitted by the 1-candle pentane unit, the 10-candle pentane Argand, and the normal "London" Argand flame. The eleventh section is on pentane, and gives the results of experiments made with pentane derived from various sources. From these results, it appears that pure isopentane cannot be relied upon as giving the same results with the 1-candle air-gas flame as the impure normal pentane prepared from rectified petroleum; but the pentane Argand enables either of these combustible materials to be employed without any practical difference in the amount of light passing under the screen, and employed as the standard. The twelfth and last section of the Appendix gives the evidence and recommendations of a deputation to the Committee from the Incorporated Institute of Gas Engineers, and the Incorporated Gas Institute.

Testing of Rich Gases.—Photometry applied to the testing of ordinary coal gas has now been considered, and a general review of proposed standards of light taken; the testing of richer gases demands some notice. It may be taken as an axiom in gas testing that the burner which, by the simple consumption of the gas in air under common atmospheric conditions, gives the highest lighting value per unit of gas consumed is that by which the illuminating value of the gas should be tested. Practically, unless the quality of the gas is known to within a few candles, it should be tested in the photometer from a number of burners, and the highest value found taken as its true illuminating power. Only Argand and flat-flame burners are admissible for testing purposes; regenerative and incandescent burners must not be used to find what is ordinarily accounted the illuminating power of the gas. Generally for gas of 18 candle power and under, an Argand burner gives the best results, and the "London" Argand is commonly used. Most gases of about 18 candle power will give nearly the same results from the standard Argand burner and a suitable flat-flame burner. For gases above this candle power, the flat-flame burner answers better than the Argand, always supposing that the flat-flame burner has the dimensions most suited to the quality of gas consumed. A few years since gas of nominally 20 candle power was supplied in Westminster, and for testing this the Gas Referees of the Metropolis prescribed a special burner, referred to in their "Notification" thus:—

"The standard burner for testing cannel gas is a steatite batswing burner, consisting of a cylindrical stem, the top of which is divided by a slit of uniform width.

	Inch.
" External diameter of top of stem, ...	0·31
Internal diameter of stem, ...	0·17
Width of slit, ...	0·02
Depth of slit, ...	0·15"

This burner gives good results with gas from 18 to 25 candle power, when used according to the Referees' directions. It serves well for testing gas having a nominal candle power lying between these limits, such as is supplied in many towns in the north of England and Scotland, and is frequently made by carburetted water-gas plants. For richer gas, batswing burners having slits more contracted must be used, and the rate of consumption decreased, the results being corrected by calculation to the normal rate of 5 cubic feet of gas per hour, which is always taken as the basis for the expression of illuminating power in this country. In France the rate of consumption required to give a constant light expresses the illuminating value of the gas; in Germany 150 litres, or 5·297 cubic feet per hour is a rate of consumption commonly used. It may be well to point out that the illuminating power of gas expressed in foreign units (*e.g.*, German candles) requires correcting, not only for the difference in value of the standard light, but also for the rate of consumption of the gas, before a comparison can be made with illuminating powers expressed in candles according to the recognized method in this country. The consumption of gas is expressed in almost all foreign communications in litres per hour; to convert to English terms the equivalent of the number of litres in cubic feet is found, the recorded illuminating power is then multiplied by five, and the result divided by the number of cubic feet gives the illuminating power at the normal English rate of consumption. Of course, correction must also be made for difference in value between the unit of light and the English standard candle, to obtain the true expression of the illuminating power of gas in the terms current here.

In like manner, when the rate of consumption of a gas is other than 5 cubic feet per hour, the illuminating power found is multiplied by five and divided by the true rate of consumption (in terms of cubic feet per hour) to find the **calculated** illuminating power at the normal rate. It is advisable in recording the results of tests made at other than the normal rate of consumption, to invariably state that the candle power is **calculated** for the normal rate, lest it be assumed that the gas was actually burnt at the normal rate. For examining rich gases large series of steatite-top batswing burners are supplied by makers of gas-testing apparatus, and those most suited to the gas examined should be tried. A slit burner gives the highest result when it is on the verge of giving a smoky flame, the consumption should, therefore, be gradually checked from the full until the flame just ceases visibly to emit smoke; and the photometrical readings should then be made, and the rate of consumption observed. For gas of 60 to 70 candle power, the most suitable burner may need a consumption of little over

1 cubic foot per hour: as the candle power diminishes the consumption is greater, until it reaches the normal rate of 5 cubic feet per hour. The development of the highest illuminating value of a gas from a slit burner is only attained by the proper proportion between the gas and air supply being maintained. If insufficient air reaches the flame combustion is imperfect, and the heat developed is insufficient to raise all the carbon particles to incandescence. The flame then smokes, and the air supply remaining constant, the remedy lies in checking the supply of gas. But if, as with very rich gases, the supply has to be cut down very greatly to prevent smoking, the proportion of the total heat developed by the small flame conducted away by the burner, and rapidly radiated, becomes large, and the effective heat remaining is insufficient to produce the proper incandescence of the carbon particles. We then have the blue portion of the flame encroaching on the normally luminous portion, and we know that the burner is too small to be used economically. It is for these very rich gases that methods of increasing the supply of oxygen to the flame, with a view to raising the temperature of the latter, find favour, and the illuminating power obtained by such means is much greater than that obtained from the pure gas in a small burner. The admixture of oxygen with the gas, as in the Tatham process, thus yields excellent results with rich gas. The illuminating value of a very rich gas is also much greater when it is diluted with a poor gas, and consumed therewith, than when it is burnt alone. Hence comes about the expression "enriching value," frequently used in reference to rich gases. Thus it is found that 1 cubic foot of a gas which, when burnt alone in the most suitable slit-burner for it, has an illuminating power of 70 candles, will raise more than 70 feet of 15-candle gas to 16 candles. *Within a small range*, the amount of a rich gas of constant value, which must be added to a poorer gas to give an increased lighting power to the latter of 1 candle, is nearly constant for different values of the poor gas, hence it is customary frequently to add a certain volume of rich gas to a known volume of poor gas of known illuminating power; then to observe the illuminating power of the mixture, and from the difference between this and the known illuminating power of the poorer constituent and the respective volumes of the two constituents of the mixture, to calculate the illuminating value of the richer gas. This will almost always be greater than the illuminating power to be obtained from it by burning it alone, and hence it is misleading to give an illuminating power calculated from the enriching value of a gas, without clearly stating the method by which the said illuminating value was found. In

considering the respective merits of rich gases, it should always be clearly ascertained how a reputed illuminating power was found. It certainly seems probable that the value of a rich gas for enriching purposes is more truly found by ascertaining the increase of illuminating power a given volume of it produces on a given volume of poor gas, than by directly observing its illuminating power; but for comparative purposes, it is desirable that the poor gas be always of nearly the same quality, and the added candle power be restricted to a small range. Until some such conventional method of testing is agreed upon, stated "enriching powers" of gases are not of much value for comparison with one another. Also, all results should be the average results of very large numbers of observations, and it is desirable that one photometrist only be engaged on each series, so that the personal equation may be constant throughout.

The Jet Photometer.—The methods ordinarily used for the exact photometry of gas have now been sufficiently discussed, but there yet remain to be discovered a few instruments that are designed to show the illuminating power of gas by very brief observation of its flame. They present the great advantage of portability, and do not necessitate the employment for comparison of a standard light, but, as may be expected, they only furnish approximately accurate results. They are, speaking generally, standardized in the first instance against samples of gas of known illuminating power. One of the most useful instruments of this class is the jet photometer, originally designed by Lowe, but since improved by the makers of photometrical appliances. It is extremely useful on a gasworks to indicate approximately the value of the gas being made, and is for this purpose generally connected to the crude gas main near the exhauster. It is

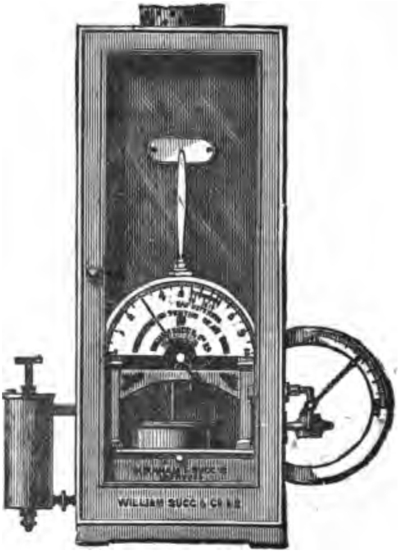

Fig. 53.—Sugg's improved jet photometer.

in this position necessary to remove carbonic acid from the gas entering the instrument by passing it through a small purifying vessel charged with clean slaked lime. Wm. Sugg & Co.'s improved form of this instrument is shown in Fig. 53, and the following are their directions for setting it up and using it, reprinted here by their permission:—

"In fixing the instrument care must be taken to have it placed perfectly level upon a firm base, so as not to be affected by vibration or other disturbing causes.

"Let it be borne in mind that, should it be thought desirable to convey the products of combustion from the room in which the instrument is fixed by means of a tube, it is indispensable that there should be an interval of at least 6 inches between it and the top of the funnel, otherwise the current of air, whether upward or downward, will materially affect the height of the flame, and, consequently, prejudice the success of the experiment; and in no case should the cap of the funnel be removed.

"Now proceed to fill the tank with water up to the overflow line. Hang on the float so that it falls from the left side of the wheel. Let the balance-weight cord have one turn round the wheel, and it will then hang close up to the wheel on the right side. Hold the wheel with the thumb and finger of one hand, and shift the pointer (which is loose on the shaft) with the other, till it stands at zero, taking care that it works freely. It is necessary, once a day, to turn off the inlet cock and open the vent cock, in order to ascertain whether the pointer will fall to zero when the pressure is off. If it does not do so, the water line must be readjusted as follows:—

"Turn on the cock between the well of the pressure gauge and the brass cylinder fixed on the left side of the instrument, which latter is the water-line regulator; when this cock is open, the water in the cylinder rises to the height of that in the well. A plunger which nearly fits the cylinder is attached to the cover of the latter by means of a fine-screwed piston rod. In the head of the piston rod is a fixed cross-bar, which is used to actuate the piston, and cause the plunger to descend into, or rise from, the water in the cylinder. If it is made to descend into the water, it causes a displacement equal to the bulk of that portion which is forced below the water line, and the water displaced goes into the well of the pressure gauge, moving the pointer in the direction above zero. If, on the other hand, the plunger is raised out of the water in the cylinder, the bulk withdrawn is immediately replaced by water from the well of the pressure gauge, and the pointer is moved in the direction below zero.

"NOTE.—The alteration of the water line is caused by evaporation, but the position of the pointer is sometimes altered by the effect of the atmosphere on the float line.

"The pointer having been properly adjusted, the communication between the well and the water-line regulator is closed, and must not be re-opened until it is required to make another adjustment of the pointer.

"Connect the apparatus with the gas, and adjust the double governor by turning on the regulating cock, lighting the jet, and weighting down the gasholder nearest it, to give $\frac{9}{10}$ or $\frac{10}{10}$ of an inch pressure. Then regulate the flame to the 7-inch mark. The pressure required to give a 7-inch flame is an index to the illuminating power—thus, 16-candle gas will give the standard 7-inch flame at ·63 of an inch pressure at the point of ignition, as shown on the dial. 14-candle gas requires ·68 of an inch to give the standard flame.

"The above instructions are for photometers rated in accordance with the gas referees' burner (Sugg's No. 1 'London' Argand)."

It will be seen that essentially this instrument is a delicate King's pressure gauge, with the addition of a jet, from which sufficient gas issues to maintain a flame of uniform length; for the ordinary jet and coal gas, the instrument is graduated for use with a 7-inch jet flame. The pressure required to give this standard 7-inch flame with ordinary coal gas is approximately a measure of the illuminating power of the gas. On the portion of the scale corresponding to the pressure required to give this flame with gas from 14 to 19 candle power is an additional series of graduations, which enable the candle power of the gas to be read off directly. On the right-hand side of the instrument case is a micrometer gas tap, on the left-hand side is a water-line regulator, which consists of a cylinder from which water is forced into the gauge-box to replace that lost by evaporation. It is necessary to daily put the water-line regulator in communication with the gauge, and adjust the level of the water in the latter until the pointer stands at the zero mark with the gas tap closed, and the vent tap open. After adjusting, the tap between the gauge and the water-line regulator is closed.

With regard to results obtained with the jet photometer, it may be pointed out that the delicacy of the instrument increases with the illuminating power of the gas, and, therefore, with a carefully calibrated specimen, the results should be more accurate with rich than with poor gas. The variations of readings of this instrument from a carefully corrected mean, may occasionally amount to over 10 per cent., and, therefore, a series of observations should always be made, and their mean taken to represent the true candle power of the gas. If this course is consistently pursued, the results obtained will correspond very closely with the true illuminating power of the gas. The instrument is largely used in large works as a means of controlling the quality of gas made in the various retort houses, and on very small works is not seldom the only photometrical appliance. Occasionally the height of the flame under constant pressure is observed, and the quality of the gas judged therefrom, but the instrument is not supplied calibrated for use in this fashion.

Illuminating Power Meter.—A rather more pretentious and almost as much used instrument is the illuminating power meter, manufactured by Wm. Sugg & Co. It is illustrated in Fig. 54, and the following is the makers' description of its construction and the mode of using it, reprinted by their permission:—

Illuminating power meter.

provided with a well-made cylindrical
on a ground swivel joint, on the top of a pillar

screwed on to a hollow rectangular base, which is firmly soldered to the outer case of an experimental meter. This base has no communication with the inside of the meter-case. That part of the pillar between the top of the base and the burner forms a cock, the gas way of which is not drilled in the usual manner, but is slotted across the plug. The sides of this gas way being parallel to each other, it follows that, unlike those cocks fitted with round-way plugs, the cock opens when the lever is turned by regular gradations until it is full open. A quadrant, divided into forty-five equal divisions, attached to the cock, enables the operator to regulate the flow of the gas to any required rate with rapidity and precision. Above the quadrant a sighting frame is fixed, having two upright pillars, crossed by a flat bar at one end, and at the opposite end a frame is fitted with blue glass. A scratch is made across the glass, exactly 3 inches above the solid part of the frame. The bottom of the opening, the top of the burner, and the termination of the thick part of the back columns, are all on the same level. The scratch on the glass, and the bar which crosses the black pillars, are also on the same level, and parallel to the three lower points just mentioned. By these arrangements the operator is enabled to adjust the height of the flame to the level of the scratch and the back bar.

"It may be observed, in passing, that if some points in the flame pass the line by about $\frac{1}{8}$ of an inch, it will make but a very slight difference to the result. There will always be small points which will look like flame, but which are only heated air. A few minutes' practice will suffice to enable any one, without previous knowledge of the instrument, to adjust the height of the flame.

"On the left side of the hollow base on which the pillar stands, is a tube which connects this base to the outlet of a double governor. This square box on the left of the meter is this governor, which serves to maintain uniformity of pressure during the time the instrument is in use. This governor is adjusted so as to give pressure enough to make the flame tail over the chimney when the regulating cock is full open.

"On the right of the hollow base is fixed a two-way cock, with a lever ending in a knob fixed to its plug. The cock is quarter stopped, so that when it is turned in one direction, as far as the stop, it is full open, and in communication with the inside of the meter, which is full of measured gas. In this position this measured gas passes through the length of the plug of the cock, and by means of a tube fixed to the end of the cock at one end, and to the inlet of the double governor at the other, it finds its way through the governor to the hollow base, and finally to the burner. While the gas is passing to the burner by this route, the measuring drum of the meter revolves; but if the lever of the clock is turned in the opposite direction until it meets the stop, another route is opened for the passage of the gas. Now, it passes directly from the inlet of the meter, without passing into the measuring drum, through the length of the plug of the cock, and out by the same tube as before, to the inlet of the governor, thence to find its way to the hollow base and the burner. In this position of the lever, the measuring drum of the meter is at rest, and the gas is unmeasured. The governor having been properly adjusted, and the meter having from $\frac{8}{10}$ to 1 inch of pressure at its inlet, this change in the position of the lever will not influence the height of the flame.

"The index hand is attached to the arbour of the measuring drum, and, therefore, revolves with it, both making a revolution in the same time. The dial is divided into a number of divisions corresponding with the illuminating power in average parliamentary standard sperm candles, of the different qualities of gas which will give a flame of 3 inches in height.

Thus, if a meter is supplied with 16-candle gas, and the flame is maintained at 3 inches, the index hand will make one complete revolution in one minute. If the meter is supplied with 12-candle gas, and the flame maintained at the 3-inch line, the hand will make one revolution and a part of another, arriving at the figure twelve in one minute. With 20-candle gas it will make less than a complete revolution in one minute, and arrive at twenty. The instrument is provided with a very accurate and strong minute clock, with one pointer hand, which makes a complete circuit of the small dial in one minute. This dial is divided into sixty equal divisions, representing seconds.

"On the right of the cylinder, which forms the outside case of the meter, is the water-line gauge, fitted with back and front glasses. At the correct water line these glasses are scratched across. On the top of the water gauge is a large nut, which can be unscrewed when it is required to fill the meter or clean the gauge glasses. The plug at the lower part of the gauge is for the purpose of running out the water if there is too much in the meter.

"In the base of the meter is a cock for the purpose of emptying all the water out of it, when it is requisite to do so. This meter should never be turned upside down for the purpose of emptying, or some water will get into the governor and connections, and probably cause trouble. For the purpose of filling the meter, a solution of 1 part good glycerine, free from acid, in 3 parts of distilled water, should be used.

"The mode of putting it into operation is very simple. Having filled the meter up to the water line scratched on the glass, connect it to the gas supply with a piece of metal tube. The inlet is a ground-union joint, fixed in the centre of the back of the instrument. Turn the lever so as to make the gas pass through the measuring drum, and let it get rid of all the air or other kind of gas in it. Light the burner and adjust the flame to 3 inches in height. Then, when the large hand arrives at 16, change the position of the lever, so as to make the gas pass to the burner without going through the measuring drum. The large hand will then stop at 16. Wind up the clock by means of the *remontoir* on the top of the meter, just in rear of the dial ring. Start the clock by moving the slide which is on the left of the meter, close to the governor. Then, when the hand of the clock is passing any one of the divisions of the minute, change the position of the lever of the bye-pass, so as to make the gas pass through the meter. When the minute hand has made one complete revolution, stop the meter by means of the lever, in the manner before described, and read off the illuminating power. The minute clock should not be stopped either before or after the observation, unless it is desired to put the clock entirely at rest."

To this full description by William Sugg, little need be added. The scale extends up to about 54 candles, but the delicacy diminishes rapidly with the higher candle powers. In some instances the reading of the illuminating power meter will agree very closely with photometer results for gas of 30 to 50 candle power, while in other similar cases there will be a divergence of as much as 3 or even 5 candles. Generally speaking, however, for such rich gases it gives tolerably reliable results, and better than might be expected from so easy a method of testing. For gas of from 15 to 20 candle power, the tendency of the instrument is to give the poorer gas a better value than it really has, and to depreciate the real value of the richer gas, thus promoting the recording of more uniform results than the gas should actually furnish. It is advisable to check the instrument against a series of photometrical tests on the description of gas on which it will subsequently be used, and to record any corrections that may be found necessary. The water level of the meter may be accurately checked by the cubic foot measure (see p. 219); the hand of the meter should pass 1 cubic foot in exactly twelve revolutions. The instrument should be protected from draughts while a reading is being taken. With such precautions, the illuminating power meter gives fairly reliable results, and is often the only means used for testing gas in small works.

Vérificateur-Giroud.—Another instrument of this class is the Vérificateur-Giroud, which is much in vogue on the Continent. This measures the consumption of gas in one minute by a jet of constant height. The consumption is measured directly from the small holder whence the gas for the jet is taken, the holder being provided with graduated scales, one of which generally purports to give at a glance the illuminating power of the gas tested. It would favour accurate results if correction of volume of the gas for temperature and pressure were made. This instrument does not appear to give better results than the illuminating power meter.

CHAPTER X.

THE APPLICATIONS OF GAS.

The subject of the proper combustion of gas for the development of light, heat, or power does not properly fall within the scope of a treatise on gas *manufacture*. But as the effective use of gas for lighting, heating, and power purposes must determine the future career of the gas industry, it behoves the gas manager to master the principles and methods of the consumption of gas for all these purposes. In this chapter, the best appliances for the use of gas will be briefly noticed, and the qualities of gas most suitable for particular purposes discussed. Priority will be given to the application of gas to lighting, which remains by far the most important of its uses. The testing of the lighting power of gas, and the lighting value of various descriptions of gas, have been dealt with in earlier chapters, therefore we may proceed at once to consider

GAS BURNERS.

Flat-Flame Burners.—The ordinary varieties of flat-flame burners, which together form the majority of all the gas burners in use at the present day, first claim attention on account of the simplicity of their construction, and the universality of their application. The value of any particular burner depends on the pressure at which the gas is supplied to it and on the quality of the gas. The quality of gas supplied throughout England is tolerably uniform, ranging from 14 to 16 candles, tested under the conditions prescribed by the Gas Referees of the Metropolis. In London the gas averages nearly 17 candles, according to the official testings by the County Council's examiners, and as it leaves the works more often above than below that quality, such may be regarded as the normal power in the Metropolis. Some large provincial towns, especially in the north, are provided with richer gas, as is almost the whole of Scotland and a large part of the United States of America. But in the majority of English provincial towns, especially those where the gas works are managed by the Municipal Authorities, and over almost the whole of the Continent of Europe, the gas supplied is unenriched coal gas from common coal, and has an illuminating power of 14 to 15 standard candles. Burners suited to this gas generally answer well for the London gas, but special ones are needed for gas of more than 18 candle power, as has already been indicated in the remarks on photometry.

Gas Pressure.—Assuming that the gas burnt is of 14 to 17 standard candles in power, the next consideration in the selection of burners is the pressure at which the gas is supplied. This is very variable, and indeed can hardly be otherwise under the influence of a continually varying consumption, and the varying levels at which it is consumed. Being specifically lighter than air, gas in a service pipe has apparently a greater pressure at a higher than at a lower level. All ordinary gauges give merely the difference between the gas pressure and the atmospheric pressure at the same spot, and it must be borne in mind that the pressure of gas, as the term is ordinarily used, is merely the expression of a comparison with a very variable standard. For ordinary purposes the common way of stating gas pressure suffices, and leads to no important practical errors. The difference in pressure between the gas in a vessel or main, and the atmosphere is expressed in the height of the column of water supported by the excess pressure of the one over the other. Two columns of water in separate vessels connected to one another at their lower ends, and exposed above to the atmospheric pressure, have *cæteris paribus* their surfaces in the same horizontal plane. If, then, one column is subjected to the pressure within a gas main or vessel instead of to the atmospheric, there may be a difference of level of the surface of the two columns, and, if there is, it will be in proportion to the difference in pressure within and without the main or vessel. By measuring the distance vertically between the planes of the surfaces of the liquid in the two columns the "pressure" of the gas is found. The ordinary gauge is a U-tube filled to about half its height with water, one limb being open to the atmosphere, and the other open at will to the atmosphere or the gas of which the pressure is to be found. With both limbs open to the atmosphere, the surface of the water in the two limbs lies in the same horizontal plane; by turning a cock one limb is shut to the atmosphere, and put in communication with the gas, and the vertical height of the level of the water in one limb above the level of that in the other limb is read off on a scale attached, and is the "pressure" of the gas in inches of water. If the water is higher in the limb in communication with the gas than in the other limb, the atmospheric pressure exceeds that of the gas, and the gas is said, in the inexact but convenient language of gas works, to be under a "vacuum" of the vertical distance between the planes of the two levels.

Pressure Gauges.—Gauges are extensively used in all parts of gas works, and a short digression on their use may be pardoned here. The U-tubes are usually of about $\frac{1}{2}$ inch internal diameter, and are filled with water, preferably coloured. The most convenient colouring material is caramel, a solution of which does not stain the glass, and is unaffected by contact with coal gas. In exposed situations, it is necessary to use in winter a liquid which does not freeze on exposure to temperatures likely to be prevalent. This may be made by adding to an aqueous solution of caramel about its own volume of a mixture of methylated spirit (free from mineral naphtha) and brown glycerine in such proportion that the specific gravity of the product is about unity. The exact proportions will vary slightly with the qualities of material used, but the proper mixture in each case is readily made on a few applications of the hydrometer. The ordinary methylated spirit sold is unsuited to the purpose, as it becomes cloudy on admixture with the caramel solution, and blurs the glass, but spirit free from mineral naphtha (which produces the cloudiness) may be obtained on proper application to the Inland Revenue Authorities. Cochineal or indigo-carmine may be used as the colouring material in place of caramel, but they are less clearly visible under all conditions of light than the latter.

Pressure in Distributing System.—The pressure of the gas in services varies very considerably, as has already been said, notwithstanding the insertion of district governors in the mains where any considerable change of level occurs. For their own sakes gas companies generally supply at as low a pressure as is consistent with proper lighting, since high pressure produces loss by leakage from cracks and faulty joints in the mains. This low pressure is often inconvenient to uses of gas for heating and power purposes, though conducive to economy in lighting where bad burners are favoured. The inconvenience is less felt if the mains and service pipes be of ample size. Gas is best consumed for lighting purposes at a low pressure—except in the case of incandescent lighting, which will be considered later—say about 0·6 inch of water. The pressure of the gas direct from the service should always be higher than this, say 1 to $1\frac{1}{2}$ inches, and may be reduced at the burner by various devices. The ordinary batswing and fish-tail burners give inferior results at a high pressure and do not themselves control it. Checking the gas tap will have the effect of reducing the supply and indirectly the pressure of the gas reaching the burner, and this is the common means adopted for regulating such burners. It must be remembered that gas issuing at high pressure from a jet induces vigorous currents of air which tend to make the flame non-luminous. The greatest luminosity is attained when the gas issues without rush or noise from the jet at precisely the rate at which it can be consumed without smoke, and without drawing more air to its flame than is necessary to just burn it under those conditions. It is necessary that the burner should be of some non-conducting material, or heat is carried away from the flame by it to the serious detriment of the light. Therefore iron is unsuitable as a material for burners, and indeed all metals are inferior. The top of the burner should invariably be of a non-conducting material, steatite being the best substance in general use. The orifice or orifices from which the gas issues should be sufficiently large to let the normal quantity of gas for the flame issue from them at a low pressure, and should merely serve to impart the desired form to it. Batswing, union, and fish-tail burners may all give good results if well constructed, though the fish-tail is generally less satisfactory than the others for gas of ordinary quality.

Governors.—Assuming that the gas is not supplied constantly at the proper pressure for consumption in well-made batswing or other flat-flame burners, it becomes necessary to introduce some controlling apparatus to secure a regular and constant pressure at the burner. Where the gas supply serves only burners at nearly the same height from the ground, and of which the number used at any time is fairly constant, a governor placed in the service pipe, and weighted to give the desired pressure at the burners, meets every requirement. Needless to say, the pressure of the issuing gas should be that most suitable for its consumption when the gas is being consumed at the number of burners normally in use, and should be tried and regulated under these conditions, and not when there is no outlet for gas. If the number of burners in use is at all considerable, the pressure of the gas in the service is very different at the time when they are in actual use, from that at the time when they are all shut off, and the governor must, of course, be regulated to give the required pressure under the normal conditions of use of the gas.

Governor Burners.—When the number of burners in use supplied from one service is very variable, or when the levels of consumption are very different, as in lofty houses, the service governor should be supplemented in some manner by governors placed near the different points of consumption. These may be on the various branches of the main supply pipe, but are more commonly on each burner. Governor burners are now made which exercise sufficient control over a widely varying range of pressure of supply of gas, and in most instances do all that is required without the aid of a governor on the main supply pipe. They have in all cases an advantage over ungoverned burners on a governed supply, since each burner can have a governor regulated to the most suitable pressure for itself, an almost essential requirement when two totally different types of burners, say the ordinary flat-flame and the incandescent, are served by the same supply pipe. The burner governor varies considerably in size and structure, but consists essentially of a chamber containing a diaphragm or float which is subjected to the pressure of the gas, and automatically diminishes or enlarges the available sectional area of the inlet or outlet pipe in proportion to the pressure of the inflowing gas. Thus, in some governor burners, the diaphragm forces a small cone more or less up the mouth of the tube leading to the burner itself in proportion to the pressure of the gas; in others a float is forced more or less over the inlet orifice, according to the pressure of the gas; the aim of all the contrivances being to vary the size of an orifice through which the gas must pass inversely with the pressure of the supply, and so when the pressure falls to give a large orifice, and when it rises a smaller orifice, and thus render the quantity of gas passing out of the burner nearly constant. The proportions of the parts determine the pressure and rate of delivery of the gas, and must be such as to give these according to the requirements of the burner. The working parts of the governors are of various materials; in some of the best the diaphragm is of sound flexible leather; in float governors the material varies, but steatite and brass form a combination not easily surpassed for efficiency and durability.

Efficiency of Flat-flame Burners.—With regard to the rate of consumption and efficiency of flat-flame burners, a few remarks may be made, which it must be especially pointed out, only apply to gas of 14 to 17 candles illuminating power. A low rate of consumption obtains a lower duty from the gas, and burners designed to consume and consuming less than 4 cubic feet per hour are very wasteful of the store of energy in the gas regarded as an illuminating agent. The low temperature existing in the flame of a flat-flame burner consuming less than 4 cubic feet per hour largely accounts for the low efficiency. Therefore, such low power burners will only be used where illumination is a very minor consideration in comparison with low absolute cost for gas. Burners consuming 4 cubic feet per hour, if of the best construction, give an efficiency of as much as 2·5 candles per cubic foot of gas consumed, or an illuminating power of about

10 candles. The best burners at a consumption of 5 cubic feet per hour give an efficiency of 2·75 to 3·0 candles per cubic foot, or an illuminating power of 14 to 15 candles. At higher consumptions a still greater efficiency can be obtained, but for general purposes good governor 5-feet-per-hour burners may be considered the most applicable. One or two give an illuminating power little inferior to that of the standard "London" Argand, at least with gas of not less than 16 normal candle power. The efficiency of flat-flame burners decreases very rapidly with a decrease in the illuminating power of the gas. It must not be supposed that so high results as those given above are furnished by the commonest metal burners such as are most generally used; they refer to the best examples of makers such as Messrs. Bray, Messrs. Sugg, &c.

Double Burner.—A device sometimes adopted to secure a good result with a burner not furnished with a governor is to cause the gas to pass through a small burner before it reaches the burner in which it is consumed. The actual burner fits over the small one, and provides a small chamber in which the gas collects, and issues at low pressure from the outer burner. The small internal burner has the effect of checking the pressure and the flow of the gas, and with high or variable pressures this method of consuming gas gives excellent results.

Argand Burners.—There are many Argand burners, but the "London" Argand, used as the testing burner in the metropolis and many other places, is by far the most efficient. The dimensions of this burner are given on p. 218; for general use it should be provided with a governor regulated to 5 cubic feet per hour, or failing that, the flame should be maintained by aid of the tap on the supply at a height of about 3 inches. The Argand burner can be used for gas of very varying candle power by regulating the supply so that a flame of a constant height of about 3 inches is obtained. As the "London" Argand is the standard burner by which the quality of a gas supply is judged, it is evident that a statement of its efficiency would be merely a statement of the quality of the gas, unless the rate of consumption was other than the normal. Of course, at 5 cubic feet per hour, and with gas testing 16·5 candles, which fairly represents London gas, the efficiency would be stated as 3·3 candles per cubic foot of gas, and is higher than that of any flat-flame burner at the same rate of consumption. It is of course assumed that the ordinary plain glass chimney is used; mica and composite glass rod chimneys, which are sometimes used in draughty positions, deteriorate the light by from 5 to 25 per cent.

Illuminating Power of Burners.—The Argand burner naturally gives an equal illumination at all points of a circumscribed circle lying in a horizontal plane. Batswing burners give a greater illumination from the flat side of the flame than from the edges. Therefore, the average illumination in a horizontal plane is less than that at the points facing the flat sides of the flame, and indeed is very little more than the illumination at points directly opposed to the edges of the flame. The illumination from the edge of a batswing flame is about 10 per cent. less than that from the face. The illumination over the surface of a sphere, of which the burner is the centre, varies much with different burners. With a good flat-flame burner it is about 10 per cent. less on the average than the illumination from the face of the flame horizontally, and is rather less than this on the average with good Argand burners. The illuminating power in different directions is so largely affected in practical use by the shades and globes employed, that no definite statement can be made which shall be generally applicable. Tests are needed for each combination of burner and shade or globe. It may be said that the opaque or nearly opaque reflecting shades fitted to reading lamps, &c., distribute the light very evenly over the solid angle, subtended by a conical surface at an angle of 30° to the horizontal, and having its apex at the flame. Fish-tail burners give a nearly uniform illumination over the horizontal plane, and a slightly lower average illumination in all directions. The distribution of the light is more uniform than with the batswing flame.

Regenerative Burners.—From the simple burners already described, we pass to those on the regenerative principle, of which the various patterns of the **Wenham** may be regarded as typical. These burners are generally of high power, and are placed at a considerable height from the floor of the room to be illuminated. They give practically no light above the horizontal plane, but a soft and very evenly diffused light beneath it. They depend for their efficient working on the heating of the air required to support the flame before it comes in contact with it. This is effected by bringing the air supply to the flame through a number of passages, the walls of which are heated by contact with the outgoing products of combustion. The method in which the air passages and flues are arranged to accomplish this end differs in the various patent regenerative burners, and constitutes the chief source of distinction between them. It is unnecessary here to describe any of the schemes in detail, as the title, "regenerative," sufficiently indicates the lines followed in the construction of the burners. The larger burners are generally furnished with a flue to convey the products of combustion, after they have parted with as much of their heat to the ingoing air as possible, outside the house or room in which the burner is placed, and thus the air of the room is not vitiated by them. Such an arrangement requires structural adaptations to admit of the flue passing through the ceiling to the external air, but wherever these are possible in a house the method should be used. The flue must be surrounded by fire-proofed material.

Regenerative lamps secure a far higher duty from the gas than simple flat-flame or Argand burners. The light afforded is nearly constant within an angle of 30° to the vertical, and outside this falls off gradually towards the horizontal plane. For practical purposes, the average light falling on surfaces where illumination is generally needed may be taken as equal to the illumination vertically beneath the burner. The efficiency of the regenerative burner increases within ordinary limits with its size. The Wenham lamp gives an efficiency of 6 candles per cubic foot for the smaller sizes, and higher than that for the larger sizes. It is, therefore, far more economical for a given illumination than any flat-flame burners, and has, moreover, great advantages over the latter, since it contaminates the air less, and produces less heat. For lighting large rooms, or rooms, shops, &c., of even moderate size, it is far superior to any of the ordinary burners, and is only surpassed for economy by incandescent gas lighting.

The Albo-Carbon Light.—The albo-carbon light, which at one time had considerable vogue, but has lately been to some extent quashed by regenerative and incandescent systems, was the outcome of numerous attempts to enrich gas at or near the point of combustion. The enriching material adopted in the albo-carbon system is naphthalene, which is gradually vaporized by the heat of the burning gas. The vapours of the naphthalene mingle with the gas on its way to the burner, and are consumed with it, greatly increasing its illuminating power. The naphthalene is placed in a spherical reservoir through an orifice closed by a gas-tight screw cap. The gas enters the reservoir, and passes from it to the burner. The burner (or burners), arranged underneath or above the reservoir in such a manner as to impart to it when lighted sufficient heat to maintain the naphthalene molten, when first lighted, consumes only the unenriched gas passing through the reservoir. As the naphthalene becomes warmed, it begins to vaporize, and enriches the gas. It is evident that this enriched gas cannot be burnt from common gas burners, but requires small, flat-flame burners, such as are used for oil gas. The enriching material is plentiful and cheap, and is likely to remain so, unless the use of the albo-carbon light increases to an extent hardly conceivable. At a consumption of gas of 4·75 cubic feet, and of naphthalene of 0·02 lb. per hour, a light of 25 candles is obtained. This shows an efficiency of 5¼ candles per cubic foot of gas, but the cost of the naphthalene must be considered in estimating the cost of the light. When purchased in quantity, the naphthalene may be taken at about one penny per pound, or per fifty hours lighting. It is evident, therefore, that the albo-carbon light is cheaper than ordinary gas burners, and gives a high illuminating power. On the other hand, the naphthalene reservoir requires recharging once or twice a week, which means a continual outlay for labour of an attendant; the reservoir cap is apt to leak unless very carefully screwed down, and if the flame becomes too large it smokes, the leaking or smoking being accompanied by a very powerful odour of naphthalene in the apartment. Indeed, where a large number of albo-carbon burners are in use, this odour is seldom absent, though, doubtless, it may nearly always be attributed to carelessness on the part of the attendants. The need of attention tells greatly against the burner. One reservoir may serve to supply one, two, or any reasonable number of burners placed in a cluster. Other attempts have been made to enrich gas just before combustion, but the albo-carbon is the only practically successful scheme.

Incandescent Gas Burner.—The incandescent gas burner is the most modern development in gas burners, and threatens to quite revolutionize the art of gas lighting. The history of incandescent lighting embodies mainly the history of the labours of one man. The common example of incandescent lighting prior to the introduction of the Welsbach light, was the **lime light**, in which a cylinder of lime is raised to incandescence by the impingement on it of a flame of hydrogen or coal gas, the combustion of which is quickened by a stream of oxygen. Only with the aid of oxygen can a sufficiently high temperature be attained by the combustion of coal gas to raise a compact piece of lime to the temperature at which it glows and emits a strong white light. For ordinary purposes of illuminating, the lime light is, therefore, not applicable. A modification of it, in which zirconia replaces lime, has been used to some extent, and is known as the **Drummond light.** The next step in incandescent lighting was the introduction by **Fahnehjelm,** of Stockholm, of his **comb,** a serrated body composed chiefly of magnesia, which was placed in the non-luminous flame of an atmospheric gas burner. The temperature of the Bunsen burner was sufficiently high to cause the material of the comb to glow, and emit a light of greater intensity than that of an ordinary gas flame. Various metal hoods and cones were devised for suspension in the flame of an atmospheric burner, with a view to giving light by incandescence. Among these were the hood of platinum wire of Prof. Lowe, of Philadelphia, and the Lewis cone of gauze, of an alloy of platinum with iridium. Unfortunately for such devices, the radiation from platinum wire, heated in a Bunsen flame, is largely thermal, and comparatively few rays of the wave-lengths, to which the eye is sensitive, are emitted from it. Hence the energy of the gas consumed under such hoods or cones is too largely expended in the production of heat for the lighting to be economical. The Fahnehjelm comb is superior to these in light-radiating power, but rapidly deteriorates on use, and has only an average effective working life of about 100 hours. In practice it gives a light of about 34 candles for 5 cubic feet of gas consumed during that period. **C. Clamond**, of Paris, devised a gauze hood or woven conical mantle, consisting of magnesia, to which, latterly, about 20 per cent. of zirconia was added. The burner was supplied with air slightly warmed by being drawn down the external surface of the chimney. The most efficient sizes of burner gave, according to Prof. W. Leybold,* an illuminating power of about 28 candles for 5 cubic feet of gas consumed, or the efficiency of the burner was about 5½ candles per cubic foot. The triumph of incandescent lighting was attained by Carl Auer von **Welsbach**, of Vienna, who introduced special methods of constructing the mantles or hoods, and more especially sought out new earths, which gave a greater percentage of rays, to which the eye is sensitive, than those hitherto used, when heated in the non-luminous flame of an atmospheric burner. The English patents protecting his inventions in this country are very numerous, but the more important ones are dated 13th March and 15th March, 1886. The use of the oxides of lanthanum, zirconium, and yttrium, thorium, erbium, and neodymium, either combined with magnesia or alumina, or in various combinations with one another, is protected by one or other of these patents. The cap or hood of one or more of these materials is made by impregnating cotton, of the desired shape, with them, and subsequently burning away the cotton, when the earth remaining retains the desired shape. The method of manufacture of the hoods is described in patent No. 15,286, dated 15th March, 1886, and is substantially the same at the present day. The chief advance since these early specifications were filed has been made in the proportions of the earths used in the mantle. The oxides of thorium and cerium, in the proportion of about 98 per cent. of thoria to 2 per cent. of ceria, are the only earths now used by the Incandescent Gas Light Company, which holds the patent rights of C. Auer von Welsbach in this country. The mantle made of these two earths, in about the above proportions, emits, when raised to incandescence, light in which there is an excess of green and blue rays, compared with the light of an ordinary gas flame or an incandescent electric lamp. It has been proved that a given illumination can be obtained with far less absorption of energy with the rays in and about the green portion of the spectrum, and the selective radiation which the Welsbach mantle exercises, is really the explanation of the true economy of the light. As far as is known at present, it appears that the earths (chiefly thoria) now constituting the Welsbach mantles, have pre-eminently the power of converting the energy of the gas consumed into light-rays of the particular wave-lengths which have the greatest illuminating effect, and that at the temperature of an ordinary Bunsen flame. All substances tried up to the present time have proved inferior to thoria in this respect, and hence no mantle, which does not contain this earth, has been made to give even approximately the same duty from the gas consumed as the present mantles of the Incandescent Gas Light Company. The fact that the patents of Carl Auer von Welsbach cover the use of thoria, gives them their great value at the present time. It may be mentioned that his incandescent light is commonly spoken of here as the "Welsbach" light, but in Germany and other parts of the Continent as the "Auer" light. The mantles, which consist of a muslin-like network of the earths, are about 3 inches in length, almost cylindrical towards their lower end, which is about 1 inch in diameter, but drawn together at the upper end to a diameter of about $\frac{1}{3}$ of an inch, so that the ultimate shape of the mantle is rather conical than cylindrical. Across the upper end of the mantle a thick loop of the material stretches, which supports the mantle when in use on the fork of a fine fireclay prop, which passes up the long axis of the mantle, and fits into a cavity in the central conical-headed rod of the burner. Through the space between this central cap and the external tube of the burner, the mixture of gas and air passes; fairly open wire gauze being stretched across the space. In principle the burner is an ordinary Bunsen, but the gauze and a small plate fitting on the outside of the tube above the air ports are provided to diminish, as far as possible, the risk of lighting back. A chimney 2 inches in diameter externally, and about 8 inches in length, fits over the mantle and upper end of the burner. When the gas is lighted the flame fills the body of the mantle and produces incandescence on its surface. The most approved forms of burner are fitted with a bye-pass and governor;

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* *Dingler's poly. Journ.*, vol. cclxxii., p. 85.

the bye-pass being arranged after the manner of a three-way cock, so that in one position of the lever a small jet only is kept burning at the foot of the prop within the mantle, while on reversing the lever, the gas is supplied to the Bunsen and lighted by the jet, to which the gas supply is simultaneously cut off. The Bunsen supply is cut off, and the jet relighted on turning the lever to its original position.

The mantle is a very fragile body, and will not bear handling or the slightest blow. For transport the mantles are dipped in a stiffening solution, generally collodion, which gives them sufficient toughness to withstand careful handling. After the mantle is in position on the prop, the stiffening material is burnt off before the gas is lighted. Suspended on the prop on the burner the mantles have a fairly long life, averaging about 500 burning hours. In many cases they last 1,000 hours or more, and it is fair to say that their power of emitting light is not diminished appreciably; certainly not by more than 20 per cent. in 1,000 hours. It is desirable that the gas-supply bracket or pendant should be fixed where it is not likely to convey sudden shocks to the mantle, and if in positions subject to strong draughts a suitable lantern should surround the burner. The bye-pass jet for lighting saves the mantle the shock from the ignition of an explosive mixture of air and gas in the chimney, which often occurs by ordinary methods of lighting. With attention to such details the life of a mantle may be very greatly prolonged.

The ordinary type of incandescent burner is designed for a consumption of about 3¾ cubic feet of gas, at a pressure of 1 inch, per hour. Under these normal conditions it gives a light of about 48 candle power. The burner requires gas at 1 inch pressure for its efficient working, and generally gives better results, at even a higher pressure. A greater consumption of gas does not, however, greatly improve results, so that it is generally advisable to use governed burners. The efficiency of the burner taking the above illuminating power and consumption is about 13 candles per cubic foot per hour, a far higher duty than that from any other class of gas burner. It is fair to state that an even higher candle power and efficiency is often claimed for the burner. The above result, however, shows that it has four times the efficiency of the "London" Argand burner. From this statement the great economy of the Welsbach system of gas lighting is evident, even when a frequent renewal of mantles and chimneys is needed.

When the light is in draughty positions, composite, glass rod, or mica chimneys answer better than the common ones. For many purposes it is desirable to alter the greenish "cold" tone of the light by the use of pink or amber chimneys or globes, but needless to say the total light passing out into the room is less when these devices are resorted to. Opal globes and shades are useful to diffuse the light. The small consumption of gas per candle power in the incandescent light gives a correspondingly low contamination of the air of a room, and the products of combustion are simply water and carbonic acid (presupposing the gas to be free from sulphur and nitrogen compounds). No carbonic oxide or acetylene is produced, as is sometimes the case with inferior gas burners of the ordinary type. The heat developed is less than that of other gas burners in correspondence to the diminished gas consumption. It is per candle power greater than that from incandescent electric lamps, being probably about three times as much. The illuminating power of the gas consumed in a Welsbach burner is not of material importance, but its calorific value is. It has been frequently proposed to use uncarburetted water gas in place of coal gas for incandescent lighting, and the system has been tried to a considerable extent on the Continent. It is evident, however, that having regard to the prevalence of good gas coal in this country, and to the value of the bye-products of coal gas manufacture that water gas is scarcely likely to supersede low power coal gas for general distribution, especially as a luminous naked flame would often be desirable and could not be at once obtained from water gas. The contemplation of two supplies, one of rich coal gas, and one of water gas, in a town cannot be seriously entertained now that the incandescent system of lighting renders gas of high illuminating power a wasteful superfluity. As soon as a sense of the shameful loss which is at present caused to the community by the compulsory supply of gas of higher illuminating power than that of gas drawn from ordinary coal at high heats of carbonization comes home to the general public, the gas industry will advance at a rate never before experienced. The substitution of a calorific in place of a photometric test, or the use of the two concurrently, the terms of the latter being much modified will herald a general employment of gas for heating and power purposes, as well as for lighting by incandescence. Incandescent lighting naturally leads to the consideration of illuminating gas as a source of heat and power. The ramifications of mains in modern towns which virtually bring into every house a source of light to be tapped at will, bring likewise an equally available source of heat and power, which are indeed generally less economically obtained from illuminating gas than from other fuels, but with greater readiness and cleanliness. The advantages of gaseous firing for most purposes have long been admitted, and the universal use of producers and generators wherever practicable shows that these advantages are considered very substantial. In these cases, however, a cheap heating, but non-illuminating, gas is made and used, and with the supply of such, a gas works is not in general concerned. In fact it is very doubtful if it would pay to distribute any of the ordinary forms of producer or generator gas through a town for general use, as the volume of gas would be enormous in proportion to its heating value, and the cost of distribution per unit of available heat would be very much greater than with ordinary illuminating gas, and would scarcely be compensated by the greater cheapness of production. Therefore it is evident, as is indicated elsewhere in this work, that the gas which can be most cheaply made and distributed for lighting purposes in most parts of this country —viz., common coal gas—is also that which will most generally be available for heating purposes, and taking into consideration the use of one system of mains for both lighting and heating gas, will also be as cheap a heating gas as can be distributed through a large area from one or two manufacturing stations. Where the area to be supplied is limited, and the consumption for heating and power purposes regular and considerable, cheaper gases may be used, but practically such cases are only found in large private or works installations. For the purpose of this work, ordinary illuminating gas need alone be considered as a generally available gas for the production of heat and power.

Calorific value of Gas.—The value of a gas for use for heating purposes and heat engines is of course primarily dependent on its calorific value. By this is meant the expression of the amount of heat developed on the perfect combustion of a given mass or volume of the gas. The unit used to express the calorific value of a substance is that commonly known as the *calorie*, and is the amount of heat required to raise 1 kilogramme of water from 0° to 1° C. Another unit frequently used in this country is that known as the *British Thermal Unit* (shortly B.T.U.), and is the amount of heat required to raise 1 lb. of water 1° F. There are 3·9683 British Thermal Units in 1 calorie.

The calorific value of a gas may be ascertained directly by completely burning a known volume of the gas under conditions in which the amount of heat evolved by its combustion can be measured, or it may be found indirectly by calculation from the composition of the gas as ascertained by a complete quantitative analysis of it, and the known heats of combustion of the components. The first method could not until recently be carried out rapidly with any considerable degree of accuracy in the results, but is now worked very satisfactorily, thanks to new forms of apparatus; the second method often involves the introduction of errors into the results owing to the imperfection of our methods for the quantitative analysis of a complex gaseous mixture, but is nevertheless very useful.

Older Forms of Calorimeter.—The older forms of calorimeter, such as that of Favre and Silbermann, were rather complicated as applied to the combustion of gases, and are now quite superseded. That of Dulong, and still more that of Thompson, are used even now when only a small quantity of gas is at disposal, and only a moderately exact result is needed. Thompson's calorimeter as used for solids is tolerably well known, and it needs only slight modification to adapt it to the estimation of the heat of combustion of a gas. An electric igniting apparatus should be added, and a supply of oxygen or air led into the copper cylinder for the combustion of the gas, which must be ignited as soon as admitted. The volume of gas passed in and consumed is known, and the rise in temperature of the water is observed, and from these data, and the constant for the instrument (generally this is an addition of about 10 per cent. to the observed value), the calorific value of unit mass or unit volume of the gas is calculated. For the obtaining of accurate results the Thompson and similar calorimeters have been superseded by the so-called Mahler "bomb," which is a modification of the bomb introduced by Andrews and much used by Berthelot. This instrument consists of a strong steel shell lined within with enamel, and provided with wires for passing an electric spark in the interior. A known quantity, say 1 gram, of the gas under examination is introduced into the bomb, and then oxygen is forced in to a pressure of about 25 atmospheres. The bomb is placed within a casing filled with water, of which the temperature is carefully noted on a delicate thermometer. The mixture within the bomb is then fired by aid of the wires, and the rise in temperature consequent on the combustion within the shell is observed in the surrounding water. The bomb is exhausted of air, and filled with the gas by repeated exhaustions and fillings, or less completely by means of tubulures which permit of a stream of the gas being blown through it until the air is expelled. The oxygen is forced in from a pressure cylinder. The carbonic acid formed in the combustion of all carbon containing gas may be estimated by being drawn through an absorption apparatus, and forms a valuable check on the experiment. The heats of combustion of the simple combustible gases and of the principal gaseous hydrocarbons have been determined with this apparatus by M. Berthelot and other observers, and the results are the most exact at present obtained. It is evident that the results directly found are the heats of combustion at constant volume; a slight correction is necessary to give the heat of combustion at constant pressure. In the figures quoted on p. 287 of values for several gases obtained by this method, this correction has been made.

Junker's Calorimeter.—For the rapid examination of the calorific value of a gas for technical purposes, an apparatus that can be more easily used than the calorimetric bomb, and by a less skilled operator, is desirable, and this has been recently supplied in Junker's calorimeter. Unlike many calorimeters, this instrument was primarily designed for estimating the heating values of gases, and has only since been adapted for liquid fuels also. The gas to be examined is led from the supply pipe, through a governor and an experimental meter, to a suitable atmospheric burner, at which it is burnt at a rate of from 3 to 30 cubic feet per hour, according to its approximate heating power. Coal gas is generally burnt at about 6 cubic feet per hour in this apparatus. To make an observation, the burner is pushed up into the cavity in a vertical double-walled cylinder. From the top of the cavity the products of combustion of the gas can only escape through tubes passing down through the space between the walls of the cylinder. The tubes converge in a common chamber at the bottom of the cylinder, and the spent gases escape thence by a shoot into the atmosphere. The annular space of the cylinder contains water, which flows in at the bottom and out at the top, and consequently is brought into contact with the outsides of the tubes down which the spent gases pass. In the water-supply and water-exit pipes delicate open-scale thermometers are placed, for the observation of the difference in temperature between the incoming and outflowing water. By the ingenious device of inserting a small cistern with overflow pipe in the course of the inlet stream of water, and supplying the water to the cistern at a greater rate than that at which it passes through the instrument, and consequently keeping the overflow continually in action, the water is supplied to the apparatus at constant pressure, and therefore always flows through it at a uniform rate. The rate is in the first instance regulated by a cock, and should be such that the exit water is from 10° to 20° warmer than the entering water when the apparatus is in use. A measuring cylinder with a mark indicating a content of 2 litres is required, as also an ordinary 100 c.c. measure graduated in cubic centimetres. The burner having been lighted and pushed up into the central cavity of the apparatus, and the stream of water flowing through properly adjusted, the temperature of the outflowing water is observed until it is found to remain practically constant. The long hand of the experimental meter is watched, and when it is passing the zero mark, the mouth of the outflow tube is put in the 2-litre measuring glass. While this glass is filling, the temperature of the outflowing water, as indicated by the thermometer placed in the exit pipe, is noted five or six times at about equal intervals, and the temperature of the inflowing water is observed twice. When the glass shows that 2 litres of water have flowed out, the gas supply is shut off and the meter read. The amount of gas consumed during the filling of the 2-litre measure is therefore known, and the average temperature of the inflowing and outflowing water is also known from the thermometer observations. Consequently it is known by how many degrees the combustion of a certain volume of the gas has raised 2 litres of water. To find the calorific value of unit volume of the gas, twice the mean rise in temperature of the water is divided by the volume of gas consumed. The gas is usually measured in this country in cubic feet and fractions of a cubic foot, hence the result found is the calorific value of a cubic foot of the gas. The results are tolerably accurate—sufficiently so, indeed, for all industrial purposes—and when needed, they may be made more exact by observing certain precautions, such as the uniformity of temperature of the gas passing the meter with that of the exit gases, and the weighing of the water passed, or, at least, measurement of it when cool.

This, and most other calorimeters, give calorific values that include the latent heat of the condensed water, and as this water in the ordinary methods of using gaseous fuel escapes as steam with the products of combustion, its latent heat is not practically available. In Junker's calorimeter, the water condensed from the combustion gases collects at the base of the apparatus, and the amount condensed on the combustion of a known volume of gas is run off into the small measuring cylinder, and its volume ascertained. For every cubic centimetre of water so condensed per cubic foot of gas burnt, a deduction of 0·6 calorie is made from the calorific value per cubic foot of the gas previously found. By this means the heat evolved on the condensation of the steam to water is eliminated from the heating value of the gas, and the result indicates what can theoretically be got from the gaseous fuel when the products of combustion are not cooled below 100° C. Hence these results form a fair basis of comparison with the heating value of the fuel as found from the work it performs in any apparatus, and give a fair indication of the efficiency of the latter.

Mode of Calculating the Calorific Value of a Gas from its Composition.—The second method of arriving at the heating value of a gas is extremely useful when an exact analysis can be had, and reliable calorimetric tests are not forthcoming. It is dependent on the heats of combustion of the various combustible gases, as found from the classical determinations of eminent physicists. The values found by M. Berthelot, working in conjunction with various other scientists, with modifications of the calorimetric bomb, are probably the most accurate, and they are given in the following table, compiled from the most recent or most reliable researches:—

HEAT PRODUCED BY THE COMBUSTION OF VARIOUS GASES.

Gas.	Heat evolved by complete Combustion at constant pressure of	
	1 Gram.	1 Cubic Foot at 60° F. and 30 inches pres.
	Calories.	Calories.
Hydrogen, ...	34·500	82·83
Carbonic oxide, . . .	2·436	81·91
Methane, ...	13·340	256·30
Ethane, ...	12·410	448·50
Propane, ...	12·010	634·30
Ethylene, ...	12·183	409·50
Propylene, ...	11·880	599·40
Acetylene, ...	12·143	379·00
Allylene, ...	11·840	568·60
Benzene, ...	9·950	955·00

These figures may be regarded as sufficiently accurate for all ordinary calculations of the heating value of a gas. It must, however, be remembered that they include the latent heat of steam, where water is a product of the combustion, and this should be deducted for most calculations of practical heating value. One gram of steam at 100° C. evolves 0·536 calorie on condensation to water at the same temperature, and hence the heat evolved by the combustion of a cubic foot of hydrogen, the water remaining gaseous at 100° C. is about 71·25 calories, and this value should be used instead of the above in calculating the practically available heating value of a gas containing hydrogen. Similarly, the heat evolved by the combustion of a cubic foot of methane becomes 232·5 calories for all practical purposes. The figures given here for the heating values of a cubic foot of various gases differ from those in most text-books, since that volume is here assumed to be under ordinary English conditions of temperature (60° F.) and pressure (30 inches), being the standard conditions to which the volumes of gas are corrected in gas works in this country. In the case of coal gas where the usual analysis (in which the hydrocarbons are not differentiated) only is available, a mean value may be taken for the calorific value of the latter. This value for ordinary 16-candle coal gas may be taken at about 670 calories per cubic foot of mixed hydrocarbons (the C_nH_m of analysts).

The heating values per cubic foot of the following gases, ascertained by this method, will, on an average, run out somewhat as follows:—

London coal gas . . . . . . = 155 calories.
Water gas (uncarburetted) . . . = 72 ,,
Siemens' producer gas . . . . = 30 ,,
Dowson gas . . . . = 37 ,,

It is, therefore, evident that London coal gas has roughly volume for volume twice the heating value of water gas, and five times that of producer gas, and that, therefore, twice as much water gas, and five times as much producer gas must be used to furnish the same amount of heat, or do the same amount of work as a given volume of coal gas. In computing, therefore, the relative cost of these gases for heating, not only must the cost of production and relative heating values be considered, but the proportionally larger mains, services, meters, &c., required by the poor gases, on account of the greater volume needed to perform a given amount of work. Producer gas is invariably, and water gas very often, made close to the place of consumption, and consequently the cost of distribution does not enter into the ordinary estimations of their value.

Amount of Air required for Combustion of Gases.—It is desirable to know roughly the volume of air theoretically necessary for the combustion of a given volume of gas in many cases, and as the theoretical amount of air required by the simple gases is known, the amount for any given mixture may be calculated. The following table gives the approximate volume of air required for the complete combustion of one volume of the gases named:—

Gas.	Volumes of Air required for complete Combustion of one volume gas.
Hydrogen, ...	2·38
Carbonic oxide, ...	2·38
Methane, ...	9·52
Ethane, ...	16·66
Ethylene, ...	14·28
Propylene, ...	21·42
Butylene, ...	28·56
Acetylene, ...	11·90
Benzene, ...	35·70

These figures show the volume of air, the oxygen of which is actually used up in the combustion. It is not sufficient merely to supply the undiluted gas with that volume, as combustion would then take place with explosive violence. Unless diluents are already present in the gas, it becomes necessary to add before combustion a very much larger quantity of air than that needed for the combustion, merely to act as a diluent, and prevent an explosion. Producer gas and similar gases have their combustion gases already largely diluted with nitrogen and carbonic acid, and, consequently, do not need a great excess of air for their safe combustion. The dilution of the combustible gas in any case is the source of a great waste of heat, as the diluent has to be raised at the expense of the heat of combustion of the gas to the flame temperature, and a great part of the heat so expended is unrecoverable, while the actual flame-temperature is much lowered by the abstraction. This loss is unavoidable, but may in some instances be considerably lessened.

Atmospheric Gas Burners.—We may now briefly consider the methods by which gas is applied for the development of heat and the supply of power. The cases in which vessels, &c., have to be heated by contact with flame are very numerous, and in these the principle of the Bunsen burner is utilized. The same principle enters into the construction of many gas fires, and is utilized in the incandescent light. The Bunsen burner may, therefore, be appropriately considered here. It primarily involves the consumption of gas after admixture with a suitable quantity of air, which ensures the complete combustion of all the gas. In the ordinary well-known patterns for laboratory use, the gas issues from a small nozzle at the base of and within a tube about $\frac{1}{3}$ inch in internal diameter and 4 inches in length. Near the base the tube is perforated, generally in two holes of about $\frac{1}{4}$ in.

diameter. In most burners these holes can be closed to any desired extent. The gas streaming from the nozzle within the tube passes up the latter, and at the same time draws air through the two holes at the base and mixes with it. When lighted at the top of the tube, the gas burns with a non-luminous flame, and formation of products of complete combustion only. If the holes at the base of the tube are too small, insufficient air will pass up, and the flame will be more or less luminous and smoky; on the other hand, if these holes be too large, an explosive mixture will collect in the tube, the flame will pass down it and ignite the gas issuing from the nozzle, and imperfect combustion will take place at the nozzle and within the tube. Many methods of regulating the air supply have been devised, and most burners are now provided with some means of altering the size of the air inlets, according to the quality and quantity of gas being consumed. Where gas of uniform quality is constantly used, and the gas tap is always turned on to the same extent, such regulation becomes unnecessary. Very many considerably modified forms of this atmospheric burner are in use, being designed to give a flame or flames more conveniently arranged for the purpose in view in each particular case. Among these are the many circular and ring burners, where the mixture of gas and air passes through wire gauze or from a large number of holes or slits in the top of the burner. Some of these burners are of very large size, but the principle involved in their construction is always the same, and they depend for their efficiency on the proper proportioning of the sizes of the gas inlet and the air port or ports, so as to obtain a mixture of gas and air in about the proper proportions for perfect combustion. Practically it is found that if the air in the mixture exceeds 80 per cent., it becomes explosive, and the flame flashes down, while if it amount to less than 70 per cent., the combustion is not absolutely complete, in cases where ordinary coal gas is being used. It is especially necessary that sufficient air be mixed with the gas when the products of combustion pass into the atmosphere of dwelling-rooms, as is often the case, as the presence of even small amounts of carbonic oxide in the products would be highly injurious to the health of the inmates. Unless the proportion of air be sufficient, contact with the surface of the vessel to be heated so lowers the temperature of the flame that the externally supplied air does not wholly complete the combustion. When the flame flashes down the tube, and the gas burns at the gas nozzle, combustion is imperfect, and quantities of acetylene are produced. This being an extremely poisonous gas, it becomes desirable to have a means of automatically preventing the flashing back of an atmospheric burner when it is exposed to draughts or to fluctuations in the gas supply tending to produce an explosive mixture in the burner tube. One of the simplest and a tolerably efficient means of avoiding this lighting back from the burner itself is to have a piece of wire gauze of suitable mesh at or near the mouth of the burner tube. Several other devices with the same end in view have recently been brought out for application to the burners of gas fires.

Gas Fires.—For heating vessels containing water, &c., direct contact with the flame of an atmospheric burner is the plan adopted. In very many gas fires, &c., designed for warming rooms, lumps of refractory fireclay, or asbestos balls or fibre, are heated by the impingement on them of a number of Bunsen flames, and the heat so received is radiated from the glowing material into the room. It becomes important in these cases that the material should have the power of emitting as large as possible a proportion of the heat received as radiant heat. Some substances are more efficient in this repect than others; the asbestos lumps of the early gas fires are not so good as some of the clay briquettes now commonly used. The disposal of the material so that radiation from as large a surface as possible takes place into the room is a matter of great importance, and some of the fires with a vertical front of fibrous asbestos or similar material up which the flame plays are among the most efficient gas fires made. With all gas fires the products of combustion should be led into a flue and thus carried out of the room, for even though the combustion be perfect, it is undesirable to allow quantities of carbonic acid to pass into the air of a room. In modern gas fires an attempt is generally made to heat the air supply before it reaches the burners, by drawing it over the heated surfaces at the back or bottom of the fire. Some few years ago Siemens produced a combined gas and coke fire, in which the regenerative principle played an important rôle, but though rather largely adopted, this fire, which did not of course wholly avoid the inconveniences attendant on the use of solid fuel, has lately dropped out of general use. Gas is very largely used for heating the water supply for baths, &c., and several specially constructed forms of heating apparatus are supplied for such purposes. Generally the water passes through a coiled pipe which is heated by the gas, and the hot water is obtained almost immediately and in a continuous stream. For roasting and, in general, heating the interior of a chamber, the heat from the gas should be as nearly as possible wholly given out as radiant heat. In such cases a number of small non-atmospheric gas jets situated within the roasting chamber is frequently used. The only objection raised to the general use of gas fires for heating rooms on hygienic grounds is that they tend to unduly dry the air of the room, but if the dryness is really found to be objectionable in any case, steps can readily be taken to renew the moisture of the atmosphere.

Gas Motors.—Gas is now so extensively used as a source of power, that the principles of the gas motor must be briefly alluded to here. For more detailed information on gas and similar engines, reference should be made to the excellent text-book on *Gas, Oil, and Air Engines*, by Bryan Donkin (Charles Griffin & Co., Limited).

In all ordinary gas engines, the power is generated by the explosion within a cylinder of a mixture of gas and air. On explosion the pressure within the cylinder is greatly augmented, owing to the change of temperature and volume of the gases, and the piston is forced out and imparts motion to a shaft. The development of the gas engine has tended to introduce several devices, by which as large a portion of the heat generated by the combustion of the gas as possible is made to do useful work, and the efficiency of modern gas engines is very much greater than that of the early patterns. The conditions which should be observed in the gas engine to obtain the greatest efficiency were first clearly indicated by Beau de Rochas, who, however, did not himself succeed in embodying them all in a motor, and it was some years after their enunciation that they were actually applied in practical gas engines. He pointed out that the cylinder surface should be as small as possible compared with the volume of the gaseous mixture, in order that surface cooling might be diminished. Hence one large cylinder is better than two small ones, and a large cylinder gives a greater efficiency than a small one, thereby explaining the greater consumption of gas per horse-power in small than in large engines. Theoretically, also, the speed of the piston should be the maximum obtainable, and the expansion the greatest possible, while the highest pressure should be developed at the beginning of the expansion. Working on these conditions, Beau de Rochas considered that the following cycle of operations should take place in the cylinder:—

I. Drawing in the charge of gas and air.

II. Compression of the charge.

III. Ignition of the charge at the dead point, with consequent explosion and expansion.

IV. Expulsion of the products of the combustion from the cylinder.

Most modern gas engines follow this practical cycle of operations, only differing essentially in the methods by which it is compassed. The gas and air are drawn into the cylinder as the piston moves out by the momentum imparted to the fly-wheel by previous working strokes. The valves admit the proper proportions of gas and air, the gas valve being sometimes attached to the governor of the engine, so that the supply is automatically diminished, and the force of the following explosion lessened, when the speed of the engine becomes too high. At the end of the stroke the admission valves close, and the piston returning, compresses the charge of gas and air in the cylinder into the comparatively small clearance space. At the end of this return stroke the charge is ignited, either electrically or by means of a red-hot tube, the temperature of which is maintained by gas burning within it. The opening to this tube is exposed when the dead point is reached, and a portion of the compressed charge passes through, and igniting, explodes the remainder of the charge within the cylinder. The expansion brought about by the explosion forces the piston out, and this stroke is the working stroke of the engine. On the return stroke an exhaust valve opens, and the spent gases are wholly or in part expelled from the cylinder. With the next forward stroke gas and air are again admitted, and the cycle of operations is begun afresh.

This cycle of operations is that of the well-known Otto gas engine, and it will be noticed that the piston makes only one working stroke for two revolutions of the crank-shaft, or two forward and two backward movements of the piston. Therefore one complete stroke is used to obtain compression of the mixture, but on the other hand, the whole cycle of operations is carried out in the cylinder itself. The flywheel must be heavy compared with that of a steam engine, in order that the energy imparted to it during the one working stroke may suffice to carry on the movements of the piston until the next working stroke. In some engines other cycles are used, and occasionally compression of the charge takes place in an outside chamber by the aid of an auxiliary pump, and the admission and compression is carried out outside the cylinder, thus doubling the number of working strokes in the latter. The power expended in working the auxiliary cylinder generally compensates for the saving of energy in the motor cylinder, and this cycle is not commonly adopted. For details of the arrangements of the admission and exhaust valves, which vary considerably in different types of motor, and for descriptions of the various engines, Bryan Donkin's text-book should be consulted. The admission valves require modification according to the description of gas consumed, in order that the proportions of air and gas may be those proper to the quality of the latter. With coal gas, from 7 to 13 volumes of air to 1 of gas constitute a suitable mixture; but with Dowson, and similar poorer gases, about 1½ volumes of air to 1 of gas are used. Consequently, about four times the volume of Dowson gas is required for the same cylinder that is needed of coal gas; and these proportions correspond approximately with the relative calorific values of the two descriptions of gas. The heat generated by the explosion is only in part utilized in work done on the piston, and the proportion so utilized represents the efficiency of the engine. In order to reduce the temperature of the cylinder walls, which become extremely hot by contact with the burning gases, before the next admission of gas and air, the cylinder is provided with a water-jacket. This necessary cooling of the cylinder walls carries off a large amount of the total heat generated. The exhaust gases are discharged also at a comparatively high temperature, in order to facilitate rapid working, and much heat is carried away with them. It will be found that of the total heat developed by the gas admitted to the cylinder, from 20 to 25 per cent. is converted into work, from 30 to 40 per cent. goes to the cooling water of the cylinder-jacket, and from 35 to 45 per cent. passes away with the exhaust gases. These figures refer to modern gas engines, of which the efficiency is high compared with those of more than twenty years ago. Nevertheless, about 75 per cent. of the heat developed is lost in the gas engine, and there does not appear to be a reasonable prospect of this loss being largely diminished as far as can be judged from our present knowledge. The high temperature developed, and consequent rapid transference of heat to the walls of the cylinder, is the chief source of loss.

Gas Motors, their Advantages and Disadvantages.—The gas engine is, at least when consuming illuminating gas, less economical for continuous working than the steam engine, especially where the large power engines are concerned. Nevertheless, it has many substantial advantages over the latter, of which the chief are (1) its great compactness, (2) rapidity and ease of starting and stopping, (3) cleanliness, and small attention needed in working. These advantages are in reality chiefly obtained through the gas consumed being produced far from the motor, and led to it by a pipe, while the boiler must necessarily be adjacent to the steam engine. The gas engine is able to take advantage of the transmission without loss, and at small cost, of its source of energy from large central stations, where the production of the gas is continuous and economical, whereas, the boiler cannot be far removed from the steam engine it supplies.

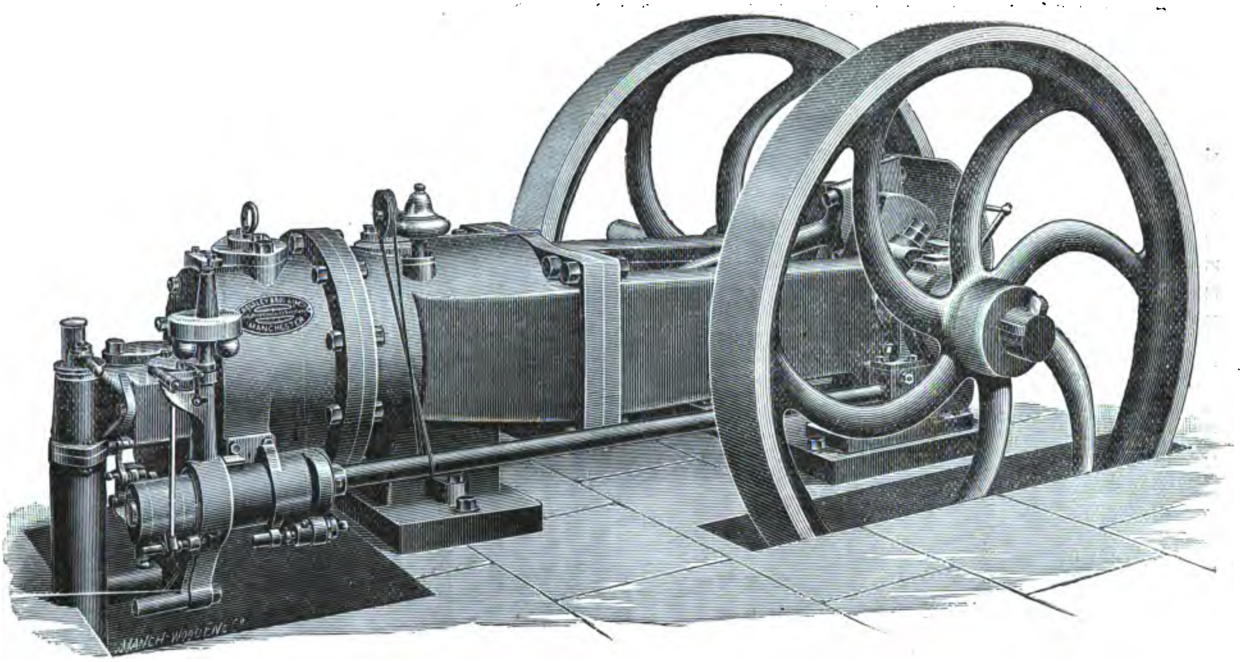

Fig. 55.—Otto-Crossley engine for electric lighting.

The gas engine, therefore, is used in many cases where steam would be quite inadmissible, and in many small industrial undertakings it has superseded manual labour. One of the chief applications of the gas engine is to drive the dynamos for small electric-lighting installations, and for this purpose, gas motors running at high speeds have been specially constructed, some of them of considerable power. One of the Otto type, designed for this purpose by Messrs. Crossley, is illustrated in Fig. 55. It is made in sizes from 6 to 14 effective horse-power, and runs at 250 revolutions per minute. These engines are suitable for the electric lighting of large private houses and institutions, while many larger ones are in use for the electric lighting of small towns. For the latter, Dowson, or water, gas is generally used.

New Applications of Gas Motors.—Recently, gas motors have found new application in the driving of tramcars and trolleys on light railways. The system most adopted so far (the Lührig) uses an ordinary gas engine, of which the flywheel is placed under a screen at the back of the seat on one side of a tramcar, and the motor itself is beneath the seat and car. The cooling water is carried in tanks on the roof of the car, and the gas for working in cylinders beneath the platforms of the car, into which it is forced to a pressure of about six atmospheres. Ordinary coal gas is generally used, and a compressing station is situated at one end of the line to recharge the storage cylinders on the cars as they arrive. The system has been tried in several German towns, the most extensive installation being at Dessau, and has given excellent results, so that considerable extensions of it may be anticipated. Other systems, some of which use air gas, or light petroleum vaporized *in situ*, have also worked well.

CHAPTER XI.

BYE-PRODUCTS.

Coke.—Coke is the bye-product which is obtained in largest quantity in the manufacture of coal gas, and a considerable excess remains for disposal even when no other fuel is used on the works. The value of the coke in the open market is, therefore, a matter of considerable importance to the management, and in some gas works, qualities of coal are purposely selected for carbonization which will yield a valuable coke, even at the expense of slightly reduced gas production. The importance to be attached to the quality of the coke produced at a gas works must ever be determined by the local prices of coal and coke and the local demand, and a few simple calculations should readily enable any gas manager to decide how much regard he should pay to the coke-yielding properties of coal in his choice of varieties of the latter. The quality of coke is tolerably easily ascertained, and its relative market value adjudged without difficulty.

Some of the more important qualities of coke have already been enumerated in Chapter i., though there it was regarded solely from the standpoint of the water-gas maker. The method of determining the amount of ash in coke is given on p. 12, and the estimation of sulphur remaining in the ash on p. 14. The total sulphur in coke, and the sulphur which forms sulphur dioxide on ordinary combustion of the fuel, may be ascertained by the methods given on pp. 11 and 26. The moisture may be ascertained with sufficient accuracy by heating about 10 grams of the roughly powdered coke in a hot-water oven for four or five hours, and weighing before and after the heating with the usual precautions. The amount of water so driven off should not exceed 5 per cent. of the total weight of the material, and may generally be kept below this percentage. No permanent gain can result to a gas works by the sale of coke saturated with water, and customers are annoyed and inconvenienced. The total sulphur in coke should not exceed 1 per cent., and the greater the proportion of this remaining in the ash, the better for the application of the coke. The ordinary Durham gas coals produce a coke far too much loaded with sulphur for metallurgical use, and consequently ordinary gas coke is only saleable for other purposes. The amount of sulphur remaining in the ash is of very minor importance for most applications of the fuel, and especially when it is used for the production of water or producer gas for gaseous firing. Many schemes have been devised for the removal of sulphur from gas coke, or for the retention of the whole of it in the ash, but the physical properties of the material present apparently insurmountable difficulties, as none of the schemes have been adopted on a large scale. Unless gas coke is made from coal exceptionally free from sulphur, or the method of destructive distillation used in gas works is greatly modified, to the detriment of the quality of the gas, there appears no immediate prospect of it being able to compete in respect of purity with oven coke for certain purposes. Fortunately there is a sufficient and remunerative outlet for gas coke for other purposes in most localities.

The ash in good gas coke should not exceed 10 per cent. of the weight of the coke, and with specially selected coals may be as low as 4 per cent. Durham gas coal of good quality gives on an average a coke yielding 8 per cent. of ash. The nature of the ash is of little moment for most purposes, but readiness to flux causes waste in furnaces through the enclosure of carbonaceous matter in the fluxed ash, and also renders clinkering more necessary and more laborious. The analysis of coke ash is seldom made in a gas works, but is a simple exercise in quantitative analysis, the materials to be sought being silica, sulphate, alumina, ferric oxide, lime, and smaller amounts of phosphate, carbonate, and magnesia. On the relative proportion of the silica and alumina to the lime and magnesia chiefly depends the fluxing properties of the ash.

The determination of the amount of ash in coke is of considerable importance as furnishing a ready approximation to its calorific value. For most practical purposes it is permissible to assume that the coke minus the ash, and a constant of about 2 per cent. of nitrogen and oxygen, is carbon. The small amount of hydrogen (generally about 0·4 per cent.) is virtually negligible in such a calculation. According to the experiments of Favre and Silbermann the heat of combustion of carbon to carbon dioxide is 8·080 thermal units, and this number may be taken for calculating the calorific value of carbonaceous fuels. The thermal unit is the amount of heat required to raise unit weight of water from 0° to 1° C. The kilogram is usually taken as the unit weight of water, and then 1 gram of carbon burnt to carbonic acid will raise 8·080 kilograms of water from 0° to 1° C. This fact is briefly expressed by saying that the calorific value of carbon is 8·080 calories or thermal units. Let us suppose that a sample of coke is found to contain 6 per cent. of ash; we may assume that it contains about 2 per cent. of nitrogen and oxygen, and consequently the carbon content may be taken at 92 per cent. Therefore, one part by weight of the coke will be equivalent to only 0·92 part by weight of carbon, or the calorific value of the coke will be only $8·080 \times 0·92 = 7·434$ thermal units. Another unit of heat, once very commonly used in this country, and still prevailing to a limited extent, is known as the British thermal unit, and is the quantity of heat required to raise 1 lb. of water 1° F. at a temperature of about 39° F. On this scale, 1 lb. of carbon burnt to carbonic acid will raise 14,550 lbs. of water 1° F. near 39° F. Therefore, the above sample of coke will have a calculated calorific power of 13,385 British thermal units. The calorific power of a fuel is sometimes given in terms of the amount of water at the boiling point which it can convert to steam. This expression of the evaporative power of a fuel is of course dependent on the latent heat of steam. Assuming the latent heat of steam to be 0·536 calorie or 965 British units, the number of pounds of water at the boiling point which a pound of fuel is capable of converting to steam, is found by dividing its calorific value expressed in calories by 0·536 or expressed in British thermal units by 965. The above sample of coke should, therefore, have an evaporative power of $\frac{7·434}{0·536}$ or $\frac{13,385}{965} = 13·87$, or 1 lb. of it should convert 13·87 lbs. of water from the liquid to the gaseous state at 100° C.

Of course the evaporative power indicated for a given fuel by the above rule is theoretical only, and is never, for very obvious reasons, attained in practice. It is, however, useful for ascertaining approximately the absolute heating value of coke, and so enabling a comparison to be made between two or more samples, errors due to imperfect or not uniform combustion in the furnace being eliminated. Also, it enables an estimate of the efficiency of a furnace to be formed. A method of practically ascertaining the calorific value of a fuel is by means of the **calorimeter.** This is more especially used for fuels of more complex composition than coke, which are not readily valued by calculation from their ultimate analysis, but it is of course equally correct for the evaluation of coke. Several forms have been devised, and some of the modern devices, which permit of the use of oxygen from compressed gas cylinders for the combustion, leave little to be desired in point of accuracy. In works the calorimeter devised by Lewis Thompson some years since is still largely used, and with careful working may be made to yield tolerably consistent results. About 2 grams of the fuel are mixed with twelve times its weight of a mixture of potassium chlorate and potassium nitrate, and the mixture is put into a small metal cylinder, which fits into a circular metal foot furnished with large perforations near its edge. A cylinder with small perforations near its base fits over the cylinder containing the combustion mixture, and is closed at the top, save where a tube, 12 inches in length, with a stop-cock at its upper extremity, joins it. The metal foot passes tolerably closely inside a glass cylinder of known content up to a mark on it. To make a determination this cylinder is filled with water to the mark. The volume of water is known, and its temperature is ascertained by a delicate open scale thermometer. A small piece of fuse is attached to the combustion cylinder and lighted, the outer cylinder is rapidly placed over it, the stop-cock closed, and the apparatus immersed quickly in the water in the glass cylinder. The products of the combustion of the coke pass out of the perforations at the base of the cylindrical cap, and impart their heat to the water in their passage through it. When the combustion is completed the stop-cock at the top of the tube is opened to allow the water to flow into the apparatus, and this is then moved up and down in the water several times to render the temperature uniform. The temperature of the water is then accurately taken. From the increase in temperature of the known volume of water the heat developed by the combustion of the given weight of coke is calculable, but certain corrections have to be made which are generally constants for the particular instrument employed. These depend on the mass and specific heat of the metal (generally copper) of which the apparatus consists, as, needless to say, part of the heat developed by the combustion goes to raise the temperature of the parts of the instrument. Occasionally a correction has to be made for a portion of the material remaining unburnt. This instrument is described and illustrated in most of the text-books on fuel; for descriptions of more modern apparatus the original memoirs of the inventors must in most cases be consulted.

With a knowledge of the percentage of sulphur, water, and ash in his coke, and its calorific value, the gas manager has sufficient data to guide him in his choice of market, and can give consumers an idea of the actual value of it compared with other fuels. The physical properties of gas coke depend mainly on the variety of coal from which it is obtained, but are also influenced by the temperature and pressure under which the distillation is carried out. It is impossible in the gas retorts now in vogue to make coke of the density of the coke-oven product. Good caking coals should produce a coke free from dust, not brittle, and tolerably porous.

It is scarcely necessary to mention here other varieties of coke, though certain oil-gas processes produce a small amount of coke from the oil used. This is of high specific gravity, but porous, and may have only 0·1 per cent. of ash, and be free from sulphur. The quality varies with the class of oil carbonized; if the oil is crude, the coke will contain ash in varying, but always appreciable, quantity: if the oil is a clear distillate, the coke will be practically free from ash. Needless to say, such a coke forms an ideal fuel for many purposes, but at present the production is very limited.

Retort Carbon.—The almost pure carbon which is deposited on the sides and top of coal-gas retorts is valuable for many electrical purposes. It is generally known on gas works as retort-scurf, and the process of detaching it from the retorts, which is carried out about every six months, is known as "scurfing." The thickness of the layer varies from 2 inches to a mere skin. It generally contains a little hydrogen, but otherwise is pure carbon. It is hard, of a dull, dark gray colour, and has a high specific gravity (about 2·4). A similar material is obtained by passing large quantities of ethylene, or of some other hydrocarbon gases, through a red-hot tube. Retort carbon is used for the manufacture of carbon plates for electric cells, for the carbon plates for electrolytic processes, and for electric arc carbon. For the second of these purposes especially, large pieces are in demand, and command a better price. The density also considerably influences some electrolytic actions in which it is employed, but no definite relation has been established between the density and the conditions of formation, and, indeed, electricians have not stated precisely what samples of carbon are most valuable for particular purposes. Gas carbon is a good conductor of heat and electricity. It is, generally speaking, too valuable for use as fuel.

Tar.—In nearly all processes for the destructive distillation of coal, oil, wood, &c., a considerable amount of dark oily liquid is produced. This liquid is styled tar; the name of the substance from the distillation of which it is derived being usually prefixed to indicate the source, and, roughly, the composition of the tar. Thus, tar produced by the destructive distillation of coal varies in composition within moderate limits, and consequently the title **coal tar** suffices to imply the approximate constitution of it to those versed in the trade terms. Thus it is, also, with **oil tar** and **wood tar**, but frequently terms are used indicating the method of destructive distillation by which the tar was obtained, thus, gas tar is a name commonly applied to the tar produced (generally from coal) in gas works, and blast furnace tar is that condensed from the spent gases of blast furnaces. Many tars have little in common except their general derivation by the destructive distillation of hydrocarbon bodies. The tar produced in the distillation of bituminous coal, according to the procedure of modern gas works, is that with which this work is chiefly concerned, and other tars can only be incidentally referred to here.

Coal tar or gas tar, as it is termed, according to the point of view of the speaker, is an exceedingly complex mixture of inorganic and organic compounds. Its composition varies according to the nature of the coal and the temperature of carbonization, but to a less extent than might be expected. The following remarks refer, where no statement to the contrary is made, to tar produced from Durham coal, without or with very little admixture of cannel, at the ordinary gas works heats:—Its specific gravity after subsidence from water is about 1·15, but may occasionally be slightly lower, or may rise to 1·20. On the large scale the bulk of the water present in a state of emulsion separates in the storage tanks, but if a sample is to be examined in which the separation is very imperfect, it may be facilitated by warming and agitating the tar in a vessel with loosely fitting top. The uses of tar in its crude state are chiefly for coating wood and metal work to preserve it, for burning as fuel, and for the manufacture of roofing felt and patent fuel. For most of these purposes a distillate or a mixture of two or more fractions of the tar answers better than the raw material, and only in works remote from a tar distillery will the bulk of the tar be burnt or otherwise used in its raw state. The manufacture of gas from tar has not for obvious reasons been carried out to any great extent in this country. Tar is, however, now largely used for retort and boiler firing on gas works, and has been used also on locomotives. It is either sprayed in by steam through specially constructed nozzles or fed by gravitation on to a bed of coke or breeze, with which it burns; in any case plenty of space must be allowed for free and complete combustion, the heat produced being radiated to the walls of the combustion chamber and flue. The heating value of coal tar is in practice about one and a-quarter to one and a-half times that of good coke weight for weight. Some of the distillates of coal tar, and many kinds of oil tar are also much used as fuel in a similar manner.

In most cases, however, the bulk of the tar produced at a gas works will find its way into the distiller's hands. The products obtained directly or indirectly from coal tar by distillation are virtually innumerable. A small scale assay of coal tar does not permit of even an approximate determination of some of the less abundant, but nevertheless valuable, constituents. The amount of the chief products of market value may be ascertained with a fair approximation to exactness in the laboratory, and this rough assay of tar is frequently carried out on a gas works for the evaluation of the tar produced. The ordinary procedure is somewhat as follows:—

Assay of Coal Tar.—A spheroidal distillation flask of about 2½ litres capacity, with side delivery tube, is dried and weighed. A litre measuring flask is filled with the tar, which has been previously agitated to separate as much water as possible, to about 2 centimetres above the mark on the neck, and the tar is then poured from it to the weighed distillation flask, time being allowed for the tar clinging to the sides of the measuring flask to run out. The tar which occupied the space above the mark in the flask will compensate for the small quantity that cannot be made to flow out. The flask may be gently warmed to facilitate the transference, as the tar becomes less viscous on heating. When the litre of tar has been transferred to the weighed distillation flask, the latter is again weighed, and the difference between this and the former weighing gives the weight of the litre of tar. Expressed in grams, and divided by 1,000, this gives the specific gravity of the tar (water being the unit) more accurately than the ordinary specific gravity bottle or hydrometer. If the tar is warmed for transference to the measuring flask, it must be allowed to cool to 15° C., and made up to the required volume at that temperature. It may then be again warmed for pouring into the distillation flask. The top of the flask is now well fitted with a cork, which is perforated to receive a thermometer with scale up to 200° C. The flask is placed on wire gauze supported on an iron ring, and clamped securely at the neck, as it generally becomes necessary towards the end of the distillation to remove the wire gauze, and to depend entirely on the clamp for the support of the flask. The delivery tube is connected up to a condenser, having its tube of about ¾ inch internal diameter, and inclined at about 15° to the horizontal. The condenser is at first supplied with cold, but afterwards with hot water, and towards the close of the distillation the water-jacket is entirely removed, or a simple glass tube substituted for the condenser. The receiver for the more volatile distillates is stood in cold water, that for the later fractions in hot water. The bulb of the thermometer should have its top on a level with the delivery tube of the flask. The flask is loosely jacketed with wire gauze, and the distillation should be carried on in a laboratory free from draughts. The arrangement of the apparatus will be seen from Fig. 56.

A ring or rose burner should be used at first, and the temperature at which distillation commences should be noted. A little pale volatile oil generally first comes over, and then the same admixed with water, the proportion of water increasing up to 100° C., when it ceases to come over, and the temperature rises suddenly. The distillation must be conducted cautiously as long as water is contained in the tar, as frothing and rather violent bumping of the tar frequently take place. The receiver is changed when the thermometer rises to 170° C., at which point the distillate becomes heavier than water, thus affording a readily applied test to indicate the time for changing the receivers. A nitrogen-filled thermometer, with scale up to 400° C., should be substituted for the one used hitherto, and warm water should be run into the condenser-jacket in place of cold. The distillate in the receiver removed consists partly of ammoniacal water and partly of light oils of a deep straw colour. The whole is put into a separating funnel and the water run off from the oil, and the volume of each carefully measured. To examine further the light oil, it will generally be necessary to obtain a further supply by subsequent distillations, which need not be conducted with the same exactitude as regards measurement and weighing of the tar and distillates. The amount of ammonia contained in the aqueous distillate is found by the ordinary distillation test for gas liquor, described on p. 323, and is, therefore, generally expressed in the conventional "ounces per gallon," but may be readily calculated to any other terms. The examination of the light oil is described later.

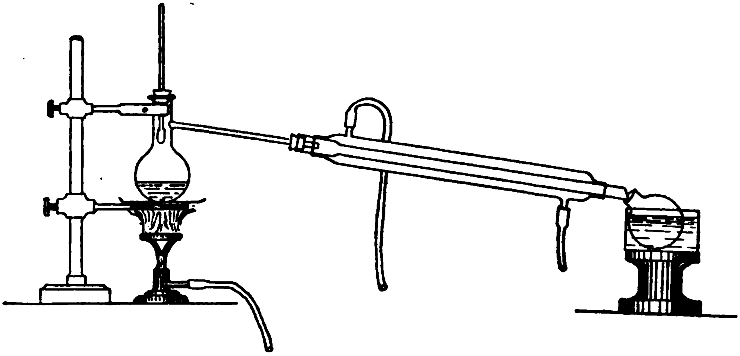

Fig. 56.—Apparatus for the assay of tar.

The distillate coming over above 170° C. is apt to choke the delivery tube through condensation of naphthalene; if naphthalene appears there the tube should be gently warmed by a gas burner. The hot water in the condenser will sustain the fluidity of the distillate until it reaches the receiver. At about 220° C. the distillate will again remain perfectly fluid on cooling, and this continues up to about 270° C., when the distillate becomes yellow, and forms a pasty mass on cooling. At this temperature the receiver is changed, and a simple wide and rather short tube substituted for the condenser. The fraction in the receiver, which has come over between 170° and 270° C., is often partially solid, from crystals of naphthalene. It should be liquefied by placing the receiver in hot water, and poured into the measuring vessel and measured while perfectly liquid, the temperature being noted. The specific gravity is taken at the same temperature, and from these figures the weight of the whole of this fraction can be calculated, and its percentage by weight on the tar found. The distillation is proceeded with until the temperature reaches about 360° C., when oil almost ceases to distil off, and dense fumes are evolved. The burner is then removed from the flask, and the latter when cold is weighed, and the amount of pitch obtained is known by the difference between this weight and that of the empty flask. The flask is then broken, and some of the pitch kept for subsequent examination. Any of the last distillate remaining in the delivery tube of the flask is run down by heating into the receiver, and the whole fraction is liquefied by standing in nearly boiling water. It is then transferred to a measuring vessel, and the volume of the oil and its specific gravity ascertained at a temperature of about 75° C., and thence the weight of the whole fraction is calculated. The specific gravity of the light oil and ammoniacal liquor having been found also, we have all the data for the statement of the percentage by weight of each fraction obtained. If the percentage by volume of the oils is required, correction of the volumes found at the higher temperatures to 15° C. must be made, and for this purpose the ordinary coefficient of expansion for petroleum oils (0·00065 per degree Centigrade) may be used without any great inaccuracy being introduced. The method of stating the results is given on p. 313.

The light oils are worked up on the large scale, chiefly for the isolation of benzene, toluene, the xylenes, and naphthas of two or three grades, the degree of purity of the products varying according to the purpose to which they are to be applied. Pure benzene, toluene, or either of the xylenes, is comparatively seldom made; certain mixtures of tolerably definite composition, but defined by physical characteristics, serve for most commercial uses. On the working scale the fraction of coal tar distilling under 110° is often received apart from that coming over between 110° and 170°, and the first fraction is then known as "first runnings," and the second as "light oil." The practice of tar distillers is by no means uniform in this matter, however, and for the purposes of a laboratory assay, it is simpler to treat the whole of the distillate up to 170° C. at one operation.

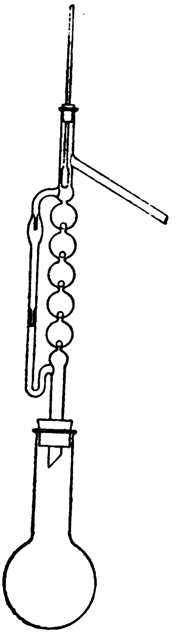

Fig. 57.—Flask and dephlegmator.

500 c.c. of the crude light oil is put into a stoppered separating funnel, and 30 c.c. of concentrated sulphuric acid added, and the mixture agitated vigorously, the funnel being cooled, if necessary, by immersion in water. After standing for half an hour, the thick black acid washings which have separated are drawn off, and 100 c.c. of dilute (say 10 per cent.) sulphuric acid are added, and the mixture is again agitated. The acid washings are drawn off on separation, and the light oil is twice washed in similar manner with pure water. It is then mixed with 30 c.c. of solution of caustic potash of 1·10 to 1·15 specific gravity, and well agitated, the potash washings being afterwards drawn off, and saved for examination. The oil is then twice well washed with pure water. The last traces of water may be removed by agitating the liquid with plaster of Paris; the quantity of oil remaining should be measured, so that some notion may be had of the loss caused by the washing process. The whole of the washed oil is transferred to a flask of about 700 c.c. capacity, to which one of Glynsky's glass dephlegmating columns is then tightly attached. Any good dephlegmator with not fewer than five bulbs may be used, but the form devised by Glynsky, which has glass spheres within the bulbs, answers well. A thermometer, with open scale registering to 170° C., is passed through the cork in the top of the dephlegmator, and the outlet tube of the latter is connected to a Liebig's condenser. The bulb of the thermometer is placed level with the outlet tube of the dephlegmator. The receiver is immersed in cold water. The flask and dephlegmator ready for connection to the condenser, are shown in Fig. 57. The distillation is carried out at as uniform a rate as pos-

sible, and the separation of the fractions made somewhat as follows:—(1) The small amount distilling under 78° C., consisting chiefly of carbon disulphide and light paraffin hydrocarbons. (2) That coming over between the above temperature and 100° C., which may be taken to approximately represent the volume of 90 per cent. benzol in the liquid. (3) That coming over at 100° to 120°, which represents the volume of commercial toluol that may be expected from the liquid. (4) That coming over between 120° and 160°, which represents roughly the volume of solvent naphtha obtainable from the light oil. The residue in the flask will go to the middle or carbolic oil fraction of the tar.

The fraction coming over under 100°, which has been assumed to be virtually 90 per cent. benzol, may be further examined by the distillation of 100 c.c. of it from a simple distillation flask of about 150 c.c. capacity, the thermometer bulb being immediately below the outlet tube. If 90 c.c. of distillate be collected by the time the thermometer indicates 100° C., the benzol may be taken to be of the grade commercially known as 90 per cent. The term is derived from the proportion of liquid that distils over below 100° C., and the terms 50 per cent. and 30 per cent. benzol have a similar origin, and are indicative of the proportion that should pass over under 100° C. The precautions to be observed in the exact testing of benzols will be found in text-books on tar products, but it may be said that the methods and, consequently, the results of different operators vary pretty considerably, the chief point of contention being the position of the thermometer in the flask. The method given above permits of results tolerably consistent, and sufficiently exact for an ordinary assay of coal tar. The 90 per cent. benzol produced from tar from Durham coal contains about 70 per cent. of benzene, 25 per cent. of toluene, 4 per cent. of light hydrocarbons (paraffins, &c.), and 1 per cent. of xylene. It has a specific gravity from 0·880 to 0·882.

Sometimes the light oil is worked up to produce 50 and 30 per cent. benzols as well as 90 per cent.; sometimes into what is known commercially as **pure toluene** and **pure xylene.** The latter consists of a mixture of the three isomeric xylenes, the meta-xylene always largely preponderant. Commonly, however, the light oil is only fractionated into the different grades of benzol and a higher boiling mixture, known as solvent naphtha, which is largely used as a solvent in indiarubber works. The pure substances are separated by the aid of tall fractionating columns, acting on similar principles to the dephlegmator already described. Benzene boils at 80·5° C., toluene at 110° C., and meta-xylene at 137° C. Solvent naphtha distils over completely between 120°

and 170° C. For further details of the testing of the fractions obtained from light oil, Lunge's *Coal Tar and Ammonia* should be consulted.

The distillate of the tar which comes over between 170° and 270° may be washed with caustic potash solution in the same manner as the light oil, the acid washing being, however, omitted, and the potash solution added to that used for washing the light oil in proportions equivalent to the relative amounts of light oil and middle oils obtained from the tar, so that a sample representative of the average potash washings of the whole distillate up to 270° is obtained. From 1 to 2 litres of the potash washings, corresponding to a known volume of tar, are taken and evaporated to about two-thirds the original volume, and any oil that remains is removed by means of a separating funnel. The concentrated washings are then treated with a slight excess of sulphuric acid of about 1·7 specific gravity. The oily liquid is collected and washed rapidly with a small volume of water, which is then separated. The oil is measured and then distilled, and the fraction distilling between 170° and 205° C. may be reckoned as **crude carbolic acid.** Besides true carbolic acid, this contains higher phenols, such as cresol, and water, naphthalene, and other impurities. The water may be separated by agitating with calcium chloride, and crystallized phenol or **carbolic acid** may then be obtained on a second distillation from the fraction passing over between 182° and 186° C. The fraction coming over about 200° consists chiefly of cresols. The determination of the relative amounts of phenol and cresols in crude carbolic acid is somewhat difficult, and is seldom done in a laboratory assay of coal tar. The methods are discussed at length in Lunge's *Coal Tar and Ammonia*, but recent German literature on the subject should also be consulted.

Naphthalene separates in considerable quantities from the cooled middle oils, and is also obtained in the distillation of the higher fractions of the light oil. It is purer if separated from the oils after the alkaline washing. The amount obtained from tar on the large scale depends largely on the method in which the distillates are worked up, and the nature of the ultimate products. The creosote oils are often sold with a large content of naphthalene. Some idea of the amount in the tar may be got by pressing that which settles from the oils, and that deposited during the distillations between fine cloths, subliming and weighing. The amount so found will generally be exceeded on working up the tar on the working scale.

The fraction of the tar distilling above 270° C. is filtered through fine canvas, and the solid matter thoroughly pressed between the canvas and folds of filter paper so as to press out as much oil as possible. The mass is then well washed with solvent naphtha, and again filtered and pressed. The resulting cake is weighed, and the percentage of anthracene in it estimated as follows (the Höchst test):—

A gram of the cake is dissolved in 45 c.c. of glacial acetic acid in a half-litre flask, to the mouth of which an inverted condenser is attached. The solution is boiled, and to it is added from a tap funnel through the inverted condenser a solution of 15 grams of chromic acid in 10 c.c. of glacial acetic acid diluted with its own volume of water. The contents of the flask must be kept in gentle ebullition and the chromic acid solution added drop by drop during a space of about two hours, at the end of which time the whole should have been used. The liquid in the flask is then kept boiling for two hours longer, when the heat is removed and the flask allowed to remain at rest for twelve hours. 400 c.c. of water is then added, and after three hours at rest, the contents of the flask are filtered, and the anthraquinone collected on the filter is washed in turn with cold water, boiling dilute solution of caustic potash (2 per cent.) and hot water. The anthraquinone is transferred by washing from the filter to a porcelain dish, and then dried at 100° C., and ten times its weight of *fuming* sulphuric acid added. The dish is heated on a hot water bath for ten minutes, and then placed in a moist atmosphere for a day. 200 c.c. of water are added, the contents of the dish poured on a filter, and the mass on the filter washed, as before described, with cold water, hot potash solution, and finally hot water. The contents of the filter are transferred to a dish, which is dried at 100° C., and weighed. The dish is then heated to drive off the anthraquinone; the dish is again weighed, and the difference between the two weighings gives the amount of anthraquinone obtained from 1 gram of the anthracene cake. This quantity multiplied by 85·58 gives the percentage of **anthracene** in the cake, and as the amount of cake obtained from a given quantity of tar is known, the quantity of anthra-

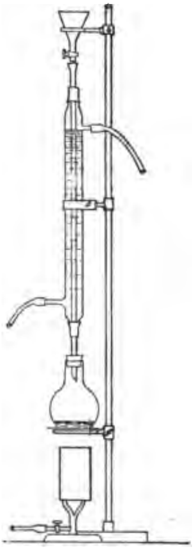

Fig. 58.—Flask and condenser for the Höchst test for anthracene.

cene obtained from the tar can be found by calculation. The arrangement of the flask and condenser for this test is shown in Fig. 58.

The bulk of the anthracene cake produced in tar distilleries goes to the alizarin makers. The chief impurities are phenanthrene, which is removed by washing with naphtha, methyl anthracene, carbazol, and paraffin. The latter is the most deleterious constituent from the alizarin makers' point of view, and as it is very difficult of removal, those samples of anthracene which are free from it command the best price. Practically it is found that the anthracene oil from common coal tar, of which the distillation has not been pushed to the farthest extent, produces good anthracene. Tar from cannel coal, and the oil obtained by distilling coal tar pitch, or pushing the distillation of coal tar to the extreme limit, yield anthracene cake contaminated with these impurities. The coal tar from the London gas works, where the use of cannel is practically abolished, and that from small works where no cannel is used for enriching the common gas, produce the best anthracene cake. The quality of the cake, on the other hand, varies considerably with the amount of pressing and washing it receives, and the method in which these operations are carried out; and the tar distilleries thus produce products of widely-different content of anthracene. Pure anthracene melts at 213° C. and boils above 360° C.

The oil from which the anthracene cake has been removed is generally added to the fraction distilling over immediately below it, and to the residues from the naphtha stills, and the carbolic acid and naphthalene manufacture. Generally there is a large amount of oil boiling between 240° and 270° C. containing considerable quantities of phenols and naphthalene, but not worked up for their recovery. This forms the basis of the **creosote** or **green oil**, the residues from other fractions being generally added to it. The total amount of this oil may be roughly estimated by adding together the oils just enumerated in the proportional amounts in which they are obtained from the tar, and thus calculating the yield on a given volume of tar. The amounts of phenols and naphthalene in creosote oil vary considerably according to the processes to which the various component oils have been subjected for the manufacture of other products. The oil is seldom purified or rectified, and serves for burning both for heating and lighting purposes in special burners, for softening pitch, and for pickling timber. Occasionally it is partially rectified, and fractions purified for use as lubricants or solvents. It may also be burnt for producing lamp black. Practically, however, it is the most useless of the products of tar distillation, and is of comparatively little value. For pickling or creosoting timber, the oil should satisfy certain tests, and for this purpose a special fraction is sometimes prepared.

The density of **creosote oil** is generally between 1·040 and 1·065, and the samples approaching the latter are perhaps to be preferred for pickling timber. The density is best taken by means of a hydrometer at 38° C. (100° F.). In many specifications, however, 32° or 35° replaces 38°. Water at 60° F. is the unit of comparison. No great importance is attached to the specific gravity when the oil is required for pickling. The oil for this purpose should be completely fluid at 38° C., and should not, on cooling, show signs of cloudiness, due to deposition of solid matter, above 35° C. Not more than 75 per cent. of the oil should distil over under 315° C. (the bulb of the thermometer being immersed in the oil). The distillate (coming over under 315° C.) from 100 c.c. of the oil is well shaken with 30 c.c. of solution of caustic potash of 1·2 specific gravity. The alkaline solution is separated from the oil by means of a separating funnel, and the oil is rewashed twice with half the former quantity of potash solution. All the washings are collected in a flask and boiled, and any traces of oil separated. The cooled alkaline liquid is then neutralized and slightly acidified with dilute sulphuric acid (specific gravity 1·20). The tar acids separate, and are removed from the aqueous liquid by means of a separating funnel, and their volume ascertained. Creosote oil should have not less than 8 per cent. by volume of tar acids when it is to be used for pickling timber; 10 per cent. is perhaps a better figure to adopt if no purification of the separated acids is attempted before measuring. It is not customary or necessary to make any enquiry into the proportions of the different phenols in the mixed tar acids. The amount of naphthalene in creosote oil intended for impregnating timber is not usually determined, but it is a very useful constituent, and will not be present in excessive quantity if the melting and solidifying points given above are not exceeded. The above instructions for the examination of creosote oil for creosoting timber are based on the recommendations of Dr. C. M. Tidy, Sir F. Abel, and Greville Williams.

Pitch.—In an assay of coal tar, the quantity of pitch is ascertained by weighing the flask, with its contents, when the distillation is completed, and subtracting from the weight so found the weight of the flask. The quality varies, and pitch is examined according to the purpose for which it is required. The bulk of the pitch made in this country is known as hard or moderately hard pitch, and softens at 60° to 80° C., and melts at 100° to 130°. It has a specific gravity of about 1·28. Pitch is very largely used for the manufacture of patent fuel, which consists mainly of small coal or coke cemented together with soft pitch. For this purpose hard pitch is often softened by an addition of the less valuable tar oils. Pitch is further used in the manufacture of certain paving and roofing compositions, and of certain varnishes. Hard pitch yields, on distillation, about 50 per cent. of coke, containing very little sulphur or ash. By extraction with benzene, carbon disulphide, and alcohol in a Soxhlet tube, pitch is reduced to about 25 per cent. of its weight of carbonaceous residue, often designated *fixed carbon.* Pitch is tested for its softening and melting points by gradually raising the temperature of a water bath, in which a ½-inch cube of the pitch is suspended, the cube being adjacent to the bulb of a thermometer on which the temperature is observed. Soft pitch can be readily kneaded between the teeth, but hard pitch crumbles to powder.

The following table shows the result of an assay of typical London gas tar (see p. 313).

Oil Tar, the bye-product of the manufacture of gas from oil, varies much in composition according to the temperature of production, the nature of the retort or producing plant, and the nature of the oil used, but is always, like coal tar, of an extremely complex nature. Owing to the smaller production, and the want of uniformity in the nature of the product, oil tar has not been studied to nearly the same extent as coal tar, and there is even doubt as to what the chief constituents are. Hence it will be surmised that it is not largely worked up for the sake of definite products, as is coal tar, and such is really the case. It is generally employed as fuel, though sometimes an attempt is made to convert it wholly into gas and coke. Some varieties yield a marketable pitch. The following information on some varieties of oil tar may serve to indicate the purposes to which it can be applied, and the methods of approximately estimating its value for them.

The tar, as deposited in the seals and condensers from ordinary forms of oil gas plant worked at the usual moderate heat, separates readily from the bulk of the water condensed with it, and may be drawn off from the latter after being allowed to settle for a day or so. The quantity of tar made is generally from 20 to 30 per cent. of the volume of oil used. It consists chiefly of hydrocarbons of high boiling point; it contains very little of the fraction corresponding to the light oil of coal tar, and only 10 to 20 per cent. of pitch. The tar generally has a density very slightly above that of water, but occasionally

Assay of London Coal Tar.

Two litres of tar were distilled completely; a further quantity for certain of the fractions, the results being in those instances calculated for 2 litres of original tar.

The tar was measured at 15·5° C., and weighed 2,384 grams. Hence the specific gravity of the tar at 15·5° C. = 1·192.

Crude Products of Distillation.	Volume of Fraction.	Temperature at which Measured.	Sp. gr. at same Temperature.	Weight of Fraction.	Percentage.		Yield of certain Products from the Crude Distillates.	Percentage by weight of certain pure products.
					By Volume.	By Weight.		
	Cub. Cen.	° C.		Grams.				
Ammoniacal Liquor,	76·0	15·5	1·014	77·0	3·80	3·53	5·8 oz. strength by distillation test, equivalent to 0·957 gram ammonia in the tar—Ammonia =	0·04
Light Oils (distilling over below 170° C.),	53·0	15·5	0·897	47·5	2·65	1·99	90 °/₀ benzol = 11 c.c. 50 ,, ,, = 13 c.c. giving 8·5 c.c. = 7·5 grams Benzene =	0·315
							Naphtha = 7 c.c.	
Middle Oils (distilling over from 170° to 270° C.),	426·0	38	1·033	440·0	...	18·46	Crude carbolic acid, sp. gr. 1·061 at 15·5° C. = 12 c.c., containing 6·3 grams crystallized Carbolic Acid = ...	0·26
							Naphthalene salts, 177 grams, containing 109·2 grams purified Naphthalene = ...	4·58
Anthracene Oils (distilling over above 270° C.),	272·0	38	1·069	290·8	...	12·20	Pressed cake, 87 grams, containing 10·44 grams pure Anthracene = ...	0·44
Pitch (medium),	...	...	...	1411·5	...	59·20		
				Grams.		Per Cent.		
Total Products, ...				2266·8		95·08		
Loss on Distillation				117·2		4·92		
						100·00		

lower. The intermediate oils, distilling over between 170° and 320° C., consist chiefly of hydrocarbons differing only slightly from those of the oil, and this major fraction of the tar may therefore be regarded as undecomposed, or but slightly changed oil. Hydrocarbons of the benzene series are nearly absent; naphthalene is not present in any quantity, nor is anthracene. If the tar is distilled, the whole of the intermediate oils may with advantage be returned to the gas retorts. This description of tar is the usual product of the Pintsch, Paterson, Avery, and similar pure oil gas plants. A sample distilled in the ordinary way gave results as shown on next page.

If the heat of gasification be higher than that ordinarily employed, the tar becomes considerably modified in composition. Aromatic hydrocarbons appear in quantity, and the volume of the intermediate oils is much diminished. The tar begins to approach in character that formed in the common carburetted water-gas plants as ordinarily worked. Tar from the latter source is generally very intimately mixed with a large volume of condensed water, and complete separation is at times impossible. For such mixtures of tar and water, heating the liquid to about 70° C. will often facilitate the separation and cause the water to settle in a layer at the bottom. The tar from these sources is generally of lower density than water, and hence tends to rise to the surface of the mixture. Separation may be effected by the aid of a centrifugal separator, on the principle of the well-known machines for separating the cream from milk. Tar from carburetted water gas is often a homogeneous mixture containing 50 to 60 per cent. of water. In its natural state distillation is dangerous and all but impossible, and separation of the water will not take place by subsidence for months unless artificially induced by one of the methods mentioned above. The dehydrated tar from the Lowe carburetted water-gas plant has a specific gravity rather less than 1, and yields on distillation from 20 to 30 per cent. of light oils, 10 to 20 per cent. of intermediate oil, and 5 to 15 per cent. of heavy oil (corresponding to the anthracene oils of coal tar). From 10 to 20 per cent. of naphthalene is deposited from the higher fractions of light oil and the middle oils, and 30 to 50 per cent. of a very glossy brittle pitch remains in the still. The light oils generally give a yield of pure benzene amounting to from 3 to 5 per cent. of the volume of the tar, but the ordinary methods for the production of commercial benzols, as applied to the light oils from coal tar, give from the light oils of oil-tar products of great impurity from the dye-makers' point of view. The light oils contain large quantities of paraffins and unsaturated hydrocarbons boiling at or near the boiling points

EXAMINATION OF A SAMPLE OF OIL TAR FROM RUSSIAN DISTILLATE OIL (0·866 sp. gr.).

The specific gravity of the tar taken by a hydrometer at 60° F. was 0·928. One litre was accurately measured at 60° F. into a weighed distillation flask, which was then weighed, and the tar distilled from it. The receiver was changed when 100 c.c. (10 per cent. by volume of the tar) had collected ; the temperature of the vapour being noted at each time of changing the receiver.

The tar weighed 928 grams, hence its specific gravity at 60° F. was 0·928, agreeing with the hydrometer reading.

No. of Fraction.	Volume c.c.	Weight grams.	Temperature.		Sp. gr. at 60° F. of Fraction.	General Properties of Fractions.
			Initial.	Final.		
			° C.	° C.		
1, . .	100	85·2	90	218	0·852	Less than 1 c.c. water came over with the first fraction ; not more than 25 c.c. of oil distilled over under 200° C. Pale straw colour.
2, . .	100	87·0	218	238	0·870	Pale straw colour ; fluidity perfect, clear.
3, . .	100	88·0	238	250	0·880	,, ,, ,, ,, ,,
4, . .	100	89·0	250	265	0·890	Straw colour ; ,, ,, ,,
5, . .	100	89·8	265	280	0·898	,, ,, ,, ,, ,,
6, . .	100	90·6	280	295	0·906	Deep greenish straw colour ; fluidity perfect, clear.
7, . .	100	91·6	295	314	0·916	Greenish-brown ,, ,, ,, ,,
8, . .	100	94·0	314	335	0·940	,, ,, ,, ,, ,, ,,
9, . .	100	97·0	335	360	0·970	Brown, slight green tinge ; ,, ,, ,,
10, . .	42	42·8	360	375	1·020	Deep brown ; ,, ,, ,,
Residue, .	...	71·9	...	...	...	Pitch ; rather hard and brittle.
Loss, . .	...	1·1				
Total = tar taken =		928·0				

Conclusions.—The tar was virtually free from water, and yielded 7·75 per cent. of its weight of pitch. The high boiling point of the first fraction points to benzene being virtually absent. No trace of deposition of naphthalene, anthracene, or solid paraffin was observable in any of the distillates. The tar appeared suitable for burning as fuel, or for returning to a gas-making plant.

of benzene, toluene, &c., and fractional distillation as ordinarily applied to coal-tar oils fails to yield similarly pure products from oil-tar oils. Thus a product could be obtained from oil tar having the specific gravity of ordinary 90 per cent. benzol, and 90 per cent. of which would distil over below 100° C., but its actual composition would be very different and the percentage of benzene contained in it much lower. This fact and the difficulty of distilling the emulsion of tar and water produced in many plants has prevented the utilization of tar from oil and carburetted water-gas plants by the tar distiller, but the larger amount of tar available from those sources may soon lead to marketable distillates being produced, though of different composition to the corresponding ones from coal tar. Only traces of phenols are found in carburetted water-gas tar, and it is generally nearly free from anthracene. Where high heats are used, the latter body is found, however, but is much contaminated with paraffins, phenanthrene, and other deleterious hydrocarbons. It may be mentioned, however, that A. H. Elliott * states that he found 2·6 to 2·9 per cent. of anthracene in tar from carburetted water gas. Water-gas tar furnishes an abundant supply of naphthalene on distillation, especially when high heats have been used in the carburetting chambers. The tar is in most works merely used for consumption as fuel under boilers, and for this purpose the presence of as much as 50 per cent. of water may be tolerated. The tar should be "atomized" by a steam or air jet, and breeze used as a fuel bed.

The liquid which is deposited in oil-gas compressing chambers, and in other places where oil gas is subjected to pressure or friction, has a very different composition to the tar. It is either practically free from water or readily separated from any mixture with it. This liquid goes by the name of "hydrocarbon" in the works where oil gas is compressed. That from the Pintsch gas has been examined by C. Greville Williams † and by H. E. Armstrong. ‡ It consists very largely of light hydrocarbons of the aromatic series, with smaller quantities of olefines and other unsaturated hydrocarbons. C. Greville Williams found the specific gravity range in seven samples from 0·76 to 0·85, and the percentage of benzene and toluene from 24·6 to 65·6. Most samples show at least 45·0 per cent. of these two constituents, and Armstrong states that the percentage in the hydrocarbon thrown down in the gas reservoirs is rarely under 50 per cent. The samples examined by Greville Williams and Armstrong

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* *Am. Chem. Journ.*, vol. vi., p. 248.

† *Chemical News*, vol. xlix., p. 197.

‡ *Journ. Soc. Chem. Ind.*, 1884, vol. iii., p. 462.

were from gas made from shale oil of about 0·840 specific gravity. Various methods for the working up of the "hydrocarbon" have been proposed and used, but the processes are chiefly carried out on the Continent. The oil which is frequently deposited in the mains and holders used for oil gas and carburetted water gas has a very similar composition to the "hydrocarbon" of the compressed oil gas works. The specific gravity varies with the distance from the manufacturing plant of the place of deposition, and also considerably according to the amount of contamination to which it has been subjected, as this liquid is an eminently good solvent for pitch, naphthalene, and other tarry matters, and also frequently holds particles of carbon in suspension. Thus a pale clear liquid obtained by vigorous scrubbing of carburetted water gas, after the grosser matters have been deposited in the purifiers and other apparatus, had a specific gravity of about 0·890, and contained 30 to 35 per cent. by volume of benzene. This liquid only yielded about 5 per cent. of pitch, but much naphthalene. Liquids naturally thrown down at earlier stages in the passage of similar gas through the mains and apparatus had specific gravities in some cases exceeding 1, and yielded sometimes as much as 30 per cent. of pitch. In all cases, however, the quantity of light oil obtained is large, and these deposited oils almost invariably contain more than 10 per cent. of their volume of benzene. Anthracene is sometimes present. Notwithstanding the high percentage of aromatic compounds in these tarry oils, the English tar distillers do not take kindly to them, as the presence of unsaturated hydrocarbons in considerable quantity prevents their being worked up satisfactorily by the old-established routine for the preparation of products from coal tar. As these hydrocarbon oils are far more valuable than the oil tar from the condensing and scrubbing plant, they should not, as is often the custom, be run into the same tar well with it. These deposited oils have a very great solvent action on the gaseous hydrocarbons and hydrocarbon vapours of illuminating gas, and should be removed from contact with it as quickly as possible, or the gas will suffer marked deterioration in illuminating power. The composition of the deposited oils is less dependent on the kind of oil used in the manufacture of the gas than on the heat employed in the production. High heats, of course, favour the production of nearly pure aromatic bodies, but at the same time produce much free carbon.

It does not come within the scope of this work to treat of the tar and benzol obtained from other sources, such as coke ovens and blast furnaces, but those interested in these competitors in the production of coal-tar products may refer to Lunge's *Treatise on Coal Tar*, and to numerous papers published by Watson Smith and others in the *Journal of the Society of Chemical Industry.*

Ammoniacal Liquor.—The ammoniacal liquor deposited in the hydraulic main and condensers and the additional water used for washing coal gas are finally run into one well, and generally handed over for the manufacture of sulphate of ammonia. The valuable constituent of this liquor is of course the ammonia, and the liquor is always disposed of or valued by its real or supposed content of that body. But since the ammonia exists in the liquor in several and various combinations, and practically never in a totally free state, the nature of the compounds must be considered before a method of estimating the whole of the ammonia in the liquor can be approved, and further consideration must be given to the composition of the liquor to learn if the whole of the ammonia in it is practically available for the production of the sulphate or other marketable salt.

The ammonium compounds in gas liquor may conveniently be divided into those which are volatile with steam, and which can, therefore, be driven off by boiling the liquor, and those which are not volatile with steam. The ammonia in the first class of salts is spoken of as **free**, that in the second class as **fixed**. The **free** ammonia in gas liquor consists almost wholly of the carbonates and sulphides, $(NH_4)HCO_3$, $(NH_4)_2CO_3$, $(NH_4)HS$, and $(NH_4)_2S$. There may also be present cyanide, and occasionally acetate and uncombined ammonia. The **fixed** ammonia is chiefly contained as chloride and thiosulphate, but there are also present thiocyanate and ferrocyanide, and if the liquor has been exposed to the air for any length of time, sulphate and sulphite; on the other hand, if the liquor is very fresh, thiocarbonate will be found in it. Besides these ammonium salts, gas liquor contains nitrogenous organic bases, tarry matters, and phenols.

Estimation of Constituents.—The relative proportions of the "fixed" and "free" ammonia in gas liquor vary very greatly according to the source of the liquor, but in the mixture of liquor from all sources, of the strength of 8 to 10 ounces, such as generally reaches the liquor works, the proportions are tolerably constant. The ammonia in the "fixed" salts will generally be about 15 per cent. of the total amount present, and almost invariably something between 10 and 20 per cent. The fixed ammonia generally is proportionately higher in weak than in strong liquor. The separate estimation of each of the acid radicles in gas liquor is tedious, and is seldom necessary in a gas works laboratory. The following hints, mainly derived in the first instance from a paper by Septimus Dyson[*] may be of service in estimating the amounts of the different salts in liquor. The carbonates and sulphides form the bulk of the salts present. The total amount of **ammonia** in these forms is approximately found by the simple saturation test described later. The amounts of **sulphuretted hydrogen** and **carbonic acid** evolved from a known volume of gas liquor on acidifying and heating may be found with tolerable accuracy by passing the evolved gases through a suitable train of apparatus containing weighed absorption bulbs and U-tubes. From the increases in weight the amount of each gas is known, and by comparison with the amount of free ammonia in the liquor, the degree to which the latter is saturated by the acid gases may be seen. The carbonate may be estimated in a measured volume of the liquor by precipitating with solution of calcium chloride rendered alkaline with ammonia, filtering off and washing the precipitate, which is then dissolved in excess of standard acid, and the solution titrated back with standard alkali. The method is accurate. Dyson's method for estimating the sulphide is to take a measured volume of liquor, add solution of zinc sulphate and a little ammonium chloride, and filter off and well wash the precipitate, which is then introduced by small portions at a time into bromine water containing hydrochloric acid. When the whole of the precipitate has been dissolved, the solution is boiled until the excess of bromine is removed, and is then filtered and the filter paper well washed. The sulphate in the filtrate and washings is estimated as barium sulphate in the usual manner, and from it the amount of sulphur combined as sulphide in the liquor is calculated. There is no exact method for the estimation of chloride and thiosulphate in gas liquor. Dyson estimates **thiocyanate** as follows:—A measured volume of liquor is evaporated to dryness, and the residue heated at 100° C. for four hours, and afterwards digested with strong alcohol, filtered off, and washed with alcohol. The alcoholic filtrate and washings are evaporated to dryness, water is added, and the insoluble matter removed by filtration. The thiocyanate in the filtrate is precipitated by solution of copper sulphate and sulphurous acid, the liquid is allowed to stand for some time, and the precipitate then filtered off and washed. Dyson then directs that the precipitate be dissolved in nitric acid, the solution boiled for some time, and the copper then precipitated by caustic soda as oxide, in which form it is weighed; the weight of cupric oxide multiplied by 0·96, gives the equivalent amount of ammonium thiocyanate. The precipitated cuprous thiocyanate may, if collected on a weighed filter and washed, and then dried at 100°, be weighed directly without introducing very great error. **Ferrocyanide** is estimated by evaporating a measured volume of the liquor to dryness, dissolving the residue in water, filtering the solution, and then adding to it solution of ferric chloride. The precipitate is filtered off and thoroughly washed with hot water. It is then digested with caustic soda, and the ferric hydrate filtered off, washed, and finally dissolved in dilute sulphuric acid, reduced, and the iron estimated by standard (say centinormal) potassium permanganate solution (see p. 94). The method of estimating the Prussian blue obtainable from a sample of liquor given on p. 327, may also serve for the rapid approximate determination of ferrocyanide. The amount of iron, multiplied by 5·07, gives the corresponding amount of ammonium ferrocyanide. The **sulphate** in liquor is determined by evaporating a measured volume to dryness, taking up the residue with water, filtering, and boiling the filtrate after adding a little hydrochloric acid. A little zinc oxide is added, the liquid is filtered, and the sulphate is then estimated as the barium salt in the usual manner. The amount of barium sulphate, multiplied by 0·566, gives the corresponding amount of ammonium sulphate.

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[*] *Journ. Soc. Chem. Ind.*, 1883, p. 229.

It will seldom be necessary to make estimations of other acid radicles in gas liquor than those enumerated above. In modern methods of working up gas liquor for the production of ammonium salts, practically the whole of the ammonia, in whatever combination it may exist in the liquor, is utilized. In the old methods in which the liquor was simply boiled for the expulsion of its ammonia, of course only that of the volatile salts was utilized, and for years liquor was valued only by its content of ammonia in these salts. As the estimation of the volatile ammonia is more rapidly and simply made than that of the total ammonia, the custom of estimating the strength of liquor by its content of volatile ammonia prevailed until quite recently in the laboratories of unprogressive gas works, to the no small advantage of the chemical works to which the liquor passed. Now, the methods of estimating the volatile ammonia in gas liquor are used only on account of their rapidity and ease of application for the control of the working of the washing and scrubbing plant on the works, and the liquor is everywhere valued and sold by its total content of ammonia salts.

An impression prevails that some of these salts are only partially or not at all broken up on distillation with lime, which is the agent invariably employed for their decomposition in liquor works. The thiocyanate is sometimes stated to be unaffected by lime, but a distillation of some of the pure salt with lime will prove that its ammonia is freely evolved. The prejudice against the presence of a large quantity of thiocyanate in gas liquor appears to date from the time when the liquor was worked into sulphate by the direct addition of sulphuric acid to it. The ammonium thiocyanate passed on undecomposed to contaminate the ammonium sulphate so manufactured. Thiocyanate is injurious to plant life, and sulphate contaminated with it was objectionable for manurial purposes. With the change in the method of working up the liquor, the thiocyanate becomes valuable, and must not be omitted from the estimation of total available ammonia in gas liquor. The laboratory determination of the **total ammonia** is founded on the principle on which the liquor is worked up on the large scale—namely, the distillation of the liquor with an alkaline base until all the ammonia is expelled. The base employed on the large scale is lime, as already stated; in the laboratory caustic soda or potash is more conveniently employed. The action is the same in either case, but the alkalies act rather more energetically than lime on the amines and other nitrogenous bodies which are, besides ammonia, present in gas liquor, and the ammonia from their decomposition is estimated in addition to that of the ammonium salts. Some operators have proposed to use magnesia, which acts less energetically than lime, but there is considerable risk of some of the ammonium salts being only partially decomposed when it is used. The difference in the results between properly conducted determinations with lime and soda is very slight, and for practical purposes may be ignored, and the more convenient soda or potash always used in laboratory work. The ammonia given off during the distillation is received in a measured volume of standard acid, which is titrated with standard alkali at the close, and the amount of ammonia evolved from a measured volume of liquor calculated from the difference in strength of the acid.

In England the strength of liquor is always stated in terms of the amount of sulphuric acid the ammonia evolved from 1 gallon of liquor is able to neutralize. The amount of sulphuric acid is stated in ounces (weight), and it is now customary briefly to speak of ammoniacal liquor as of so many "ounces" strength, meaning thereby the weight in ounces of real sulphuric acid that a gallon of the liquor would exactly neutralize. To readily obtain the results of estimations of strength of liquor expressed in these terms, it is desirable to make a standard acid of such a strength that calculation of results is avoided. Such an acid is that of which 100 c.c. contain 10 grams of real sulphuric acid (H_2SO_4). This is commonly spoken of as "10 per cent. acid."

It may be made up of approximately the right strength by diluting 16¼ ounces by weight of the ordinary pure concentrated sulphuric acid (specific gravity 1·84) to 1 gallon with distilled water, or by making up 101·5 grams or 55·1 c.c. of the same concentrated acid to 1 litre. The dilute acid so obtained should, when cool, have its specific gravity taken with a delicate hydrometer. The specific gravity should be 1·0644 at 60° F.; the correct specific gravity at other temperatures is given in the appended table, which is, I believe, due to Lewis T. Wright.

Specific Gravity
at different temperatures of so-called "10 per cent." sulphuric acid for liquor testing.

Temperature.	Specific Gravity.	Temperature.	Specific Gravity.	Temperature.	Specific Gravity.
50° F.	1·06640	57° F.	1·06503	64° F.	1·06356
51° „	1·06621	58° „	1·06482	65° „	1·06335
52° „	1·06602	59° „	1·06461	66° „	1·06314
53° „	1·06583	60° „	1·06440	67° „	1·06293
54° „	1·06564	61° „	1·06419	68° „	1·06272
55° „	1·06545	62° „	1·06398	69° „	1·06251
56° „	1·06524	63° „	1·06377	70° „	1·06230

The trial acid, if of incorrect specific gravity, should be diluted until corrected; when the hydrometer shows it to be as nearly as possible of the proper specific gravity the sulphuric acid in it should be estimated against a weighed amount of pure sodium carbonate, or by taking a measured volume of the acid, and making the determination as barium sulphate in the manner described earlier. 10 c.c. of the acid should yield 2·378 grams of barium sulphate. If the hydrometer is accurate and has a very open scale, and the original concentrated acid was known to be pure, the determination of the specific gravity will suffice for standardizing the acid, but if either of these conditions is wanting the strength should be ascertained by one of the analytical methods mentioned, and any deviation from the proper strength corrected.

In addition to the standard acid, a standard alkali of corresponding strength is required. This is generally ammonia, but soda or potash may be used if preferred (with methyl-orange as indicator). Ammonia solution of approximately the right strength may be prepared by diluting 117 c.c. of the strongest liquor ammoniæ (specific gravity 0·880 at 60° F.) to 1 litre, or

19 fluid ounces to 1 gallon. The solution so prepared is titrated against the standard acid, and should exactly neutralize its own volume of the acid. If it does not, liquor ammoniæ or water must be added until the solution is exactly of the required strength. If kept in a bottle well corked with a caoutchouc plug, the standard ammonia solution will not change in strength on prolonged storage, but it should be checked against the standard acid twice a week if in daily use, and on each occasion if less often used, and any deficiency in strength remedied by a further addition of ammonia.

For carrying out the distillation test, which was applied to gas liquor by Wills, and is often referred to under his name, the following apparatus is generally used:—Two pipettes of 16 units capacity; the cubic centimetre is the unit used in some laboratories, the septem that favoured in others. A burette, graduated on the same system as the pipette used into divisions of 0·1, of 16 units capacity. The necessity for subtracting the amount of standard ammonia used at each test in this burette from 16 is avoided if the burette be graduated upwards, zero being the bottom and 16 the top division on it. But, of course, any ordinary burette will serve. A flask of about 500 c.c. capacity fitted with caoutchouc plug, through which passes the stem of a tap funnel reaching nearly to the bottom of the flask, and also a ¼-inch delivery tube leading to an absorption bulb, or a flask which will contain the standard acid. The end of the delivery tube, which passes through the plug in the distillation flask, should be cut slantwise to facilitate the return of condensed liquid, and above the cork the tube may, with advantage, be expanded to a bulb before it bends horizontally towards the bulb or flask containing the acid. The bulb will hinder the passage along the exit tube of any liquid which may have been bumped up during boiling from the liquid in the flask. Bumping of the liquid will not, however, occur if half a dozen small pieces of clean platinum foil be placed in the flask. For the acid, the ordinary bulbed tube used for absorptions may be used, or a spiral condenser may be connected to the delivery tube, and the outlet of it dip beneath the standard acid contained in a 200-c.c. flask. The best method of heating the distillation flask is by means of an Argand lamp, with the interposition of a piece of wire gauze between the top of the chimney and the flask. In laboratories where the sand bath is not discredited, it is used for the purpose. The apparatus fitted up for an estimation is shown in Fig. 59.

The determination is made in the following manner:—16 c.c. of the standard acid is measured out with one of the pipettes into the small flask, and is diluted with its own volume of water. The flask is placed beneath the spiral condenser, so that the delivery tube of the latter dips under the surface of the acid.

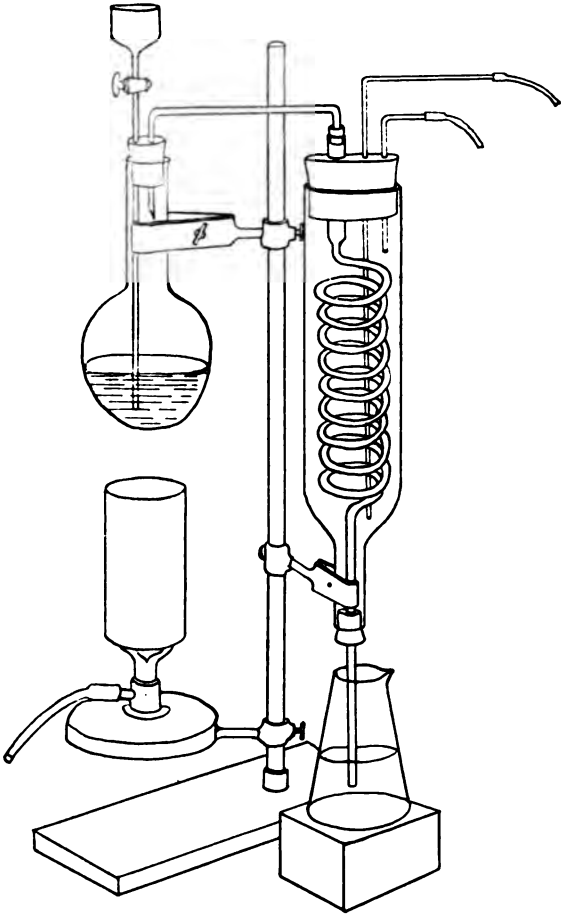

Fig. 59.—Apparatus for determining strength of gas liquor.

16 c.c. of the liquor to be tested is taken with the second pipette, and delivered into the large flask through the tap funnel. The connections are made quite tight, and about 100 c.c. of caustic potash solution, of 1·1 specific gravity, is poured in through the

tap funnel. The tap is then closed, the Argand burner lighted, and the liquid in the flask raised gradually to boiling, and then kept boiling gently until it is nearly brought to dryness. The ammonia expelled from the liquor passes through the condenser, and is absorbed by the standard acid. When the distillation is carried far enough, the delivery tube is disconnected from the top of the condenser, and the spiral of the latter washed through with a little distilled water, which passes into the flask containing the acid. The latter is removed, the burette is filled with standard ammonia solution, and the acid in the flask titrated with it, tincture of cochineal being a convenient indicator generally to hand on gas works. Since 16 c.c. of the standard acid is exactly neutralized by 16 c.c of the standard ammonia, the amount of standard ammonia used in this titration to neutralize the free acid in the flask must be deducted from 16 to give the number of cubic centimetres of the standard acid which the ammonia in 16 c.c. of the liquor neutralized. This number is the strength of the liquor expressed in "ounces" according to the definition given above. This is evident from the fact that 1 gallon of the standard acid contained 16 ounces of real sulphuric acid, and the 16 c.c. measures used for measuring the acid and liquor have capacities expressed by the same submultiple of the number of cubic centimetres in a gallon, and, therefore, may represent when used in the manner described, a diminutive gallon, and each cubic centimetre of standard acid will represent $\frac{1}{16}$ of 16 ounces, or 1 ounce of real acid. 16 c.c. of liquor, representing on the same scale a gallon of liquor, the number of cubic centimetres of standard acid the ammonia from it neutralizes will express the strength of the liquor in "ounces," since, if the standard acid is correctly made up, and the test has been accurately carried out, the ammonia from 1 gallon of liquor would exactly neutralize the same number of ounces of real sulphuric acid, or sulphuric monohydrate. In these instructions "septem," or any other unit, may be read for "cubic centimetres," but the same unit must be used throughout. Boiling the liquor with caustic potash solution nearly to dryness introduces a slight error, due to the liberation of ammonia from other nitrogenous bodies in the liquor, but this error may be disregarded for commercial purposes.

Objection is often raised to the somewhat arbitrary standard of "ounces" used for expressing the strength of gas liquor, and certainly its *raison d'être* is not now very evident. The system is, however, widely used, and as it in no way militates against the delicacy of testing, many of the objections raised to it fall to the ground. The strength of liquor may be expressed in ounces and fractions of an ounce to any desired degree of accuracy, and on this score the plea for the change to a "percentage of ammonia" system is not valid. The arguments for the change have been put forward at some length by J. Carter Bell,* but do not appear to require its urgent adoption unless supplemented by more cogent ones. The weight of actual ammonia in liquor may be readily calculated from the "ounce" strength. One gallon of one "ounce" liquor contains 0·347 ounce of ammonia, therefore the weight of ammonia in a gallon of liquor is found by multiplying its "ounce" strength by 0·347, the result being expressed in ounces avoirdupois of real ammonia. One litre of one "ounce" liquor contains 2·17 grams of ammonia. From this figure the percentage of ammonia in liquor of known "ounce" strength may be deduced, for 100 c.c. of one "ounce" liquor contain 0·217 gram of ammonia, and, therefore, 100 volumes of liquor of x "ounces" strength contain $x \times 0{\cdot}217$ part by weight of ammonia, the unit of volume being the volume of one part by weight of distilled water. The true percentage by weight of ammonia may be readily calculated if the specific gravity as well as the "ounce" strength of the liquor is known. The most common product of liquor works is ammonium sulphate, and the yield of gas liquor is sometimes expressed by the weight of this article obtainable from it. The weight of ammonia multiplied by 3·882 gives the theoretically obtainable weight of ammonium sulphate.

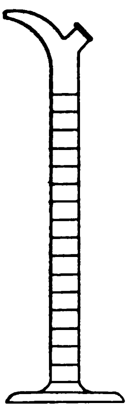

Fig. 60.—Bink's burette.

The "free" or volatile ammonia in gas liquor may be estimated approximately by the aid of the standard acid used for the distillation test. 16 c.c. of the liquor is measured by means of a pipette, and diluted to about 100 c.c. A few drops of methyl-orange are added, and the standard acid is then run in from a burette until the ammonia is neutralized. The number of cubic centimetres of acid required gives the strength of the liquor in volatile ammonia only expressed in "ounces." Litmus is valueless as an indicator owing to the carbonic acid and sulphuretted hydrogen evolved from the liquor, and cochineal is far inferior to methyl-orange. This test is often known as the "saturation test." It may be carried out by the scrubber attendants by the aid of a Bink's burette (Fig. 60), from which the standard acid is delivered in small quantities at a time into the measured volume of liquor contained in an open basin. The point of neutrality is ascertained by bringing a drop of the liquid on the end of a glass stirring rod on to a piece of litmus paper after each addition of acid. The liquor should be stirred vigorously with the rod before each trial. The results are, of course, only approximate, but this rough method of testing is very useful for controlling the working of washers and scrubbers. The standard acid should be made up under the supervision of an analytical chemist, as unless it be correct, the results obtained will be quite valueless for any purpose.

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* *Journ. Soc. Chem. Ind.*, 1883, p. 109.

In the estimation of ammonia by the distillation method in liquor of over 16 ounces strength, two pipettefuls of standard acid should be taken in the small flask, and the number of cubic centimetres of standard ammonia used in titrating should be deducted from 32 instead of from 16, to give the strength of the liquor.

Cyanides from Coal Gas.—Many processes have been devised for the extraction of cyanogen compounds from coal gas, with a view to the production of Prussian blue or other ferrocyanide. One that has been in operation on a considerable scale for some time past, consists in running into the washer scrubber a solution of an iron salt, or a liquid containing iron sulphide or hydrate in suspension, in place of pure water or weak liquor. The cyanides in the gas combine with the iron, and after a time a liquor is obtained containing a considerable quantity of ammonium ferrocyanide. This liquor is worked up into high quality Prussian blue and potassium ferrocyanide, but this process is not generally carried out on the gas works, and some secrecy is observed as to the methods adopted. The gas works chemist will, where the process is adopted, generally be called upon to estimate the amount of ferrocyanide in the liquor, in order to determine the value of the latter.

This may be done easily and with tolerable exactness, by weighing the Prussian blue produced from a given volume of the liquor. In order that the Prussian blue may be of uniform composition, and results strictly comparable, it is advisable to follow invariably a certain order of procedure in its formation. The following method is recommended:—Take 10 c.c. of the filtered liquor, and add it to 100 c.c. of dilute ($\frac{1}{3}$ concentrated acid) hydrochloric acid. Then wash the liquid so obtained into 50 c.c. of nearly saturated solution of ferric chloride, well mix, and then filter. The filter used must have been weighed with the usual precautions, or, for an approximate estimation, two filter papers may be balanced by clipping the heavier until they are of the same weight. One is fitted within the other, and the filtrate passes through both, and they are, consequently, both subjected to similar treatment and influences. The Prussian blue is filtered off on the weighed filter or balanced filter papers, and is then very thoroughly washed with hot water. It is generally necessary to hasten the filtration and washing by the aid of a filter pump. The filter and contents are dried in a hot-water bath, and washed with dehydrated carbon disulphide, again placed in the hot-water bath for a short time, left to cool in a desiccator, and weighed. The two balanced papers are placed, one in each pan of the balance, and the difference in their weights gives the amount of Prussian blue. If the weighing is made on the gram system, the number of grams from 10 c.c. of liquor is equivalent to the number of pounds of blue which could be obtained from a gallon of the liquor. The washing with carbon disulphide is intended to remove the small quantity of sulphur carried down with the Prussian blue.

In some cases it is preferable to digest the Prussian blue after it has been well washed with caustic soda, then to filter off the ferric hydrate, wash it, and dissolve it in dilute sulphuric acid. The iron is then reduced by zinc or magnesium to the ferrous state, and the solution titrated with decinormal solution of potassium permanganate. The amount of iron so found, multiplied by 5·07, gives the amount of ammonium ferrocyanide in the liquor.

The total ammonia in the iron liquor that has been used in a washer to recover the cyanides, is found on a clear portion of it in the manner already described under ammoniacal liquor. If the liquor has been kept in contact with crude gas for a long period, in order to make it rich in ferrocyanide, the ammoniacal strength will often be over 20 ounces. The amount of Prussian blue will range from 0·1 to 0·8 lb. per gallon of liquor.

Thiocyanate or sulphocyanide is less valuable than ferrocyanide, and steps are seldom taken for its recovery from gas products. It may be estimated in liquors or washings by the method given on p. 319. In most cases the presence of thiocarbonate and other compounds will prevent its estimation volumetrically.

Spent Oxide of Iron.—Oxide of iron which has been used for gas purification is valuable chiefly in virtue of the free sulphur it contains, but when it has been used under some conditions it may also contain appreciable quantities of ammonia and cyanogen compounds, which are sometimes extracted commercially. The gas works chemist is, however, generally concerned only with the estimation of the **sulphur** in spent oxide. This estimation is always made by extracting the sulphur from a known weight of the spent oxide with carbon disulphide. Slight differences in the method of conducting the estimation are found in different laboratories, but essentially the methods are similar.

It is generally desirable to know the amount of **moisture** in the material, and its removal is essential to a correct estimation of the sulphur. To determine it, and to prepare the oxide for the sulphur estimation, 100 grains of the roughly granulated sample, which should correctly represent the bulk under examination, are weighed out on a tared watch glass, and placed in a hot-water oven for from two to three hours. It is not advisable to leave the oxide in the hot oven for a much longer period. The loss in weight gives the moisture in the 100 grains of material. The dried oxide is now ready for transferring to the extraction apparatus; the transference should be effected without loss. In general chemical laboratories a Soxhlet's extraction apparatus will be to hand, and it serves excellently for this determination. Blount's form of the apparatus is commendable as being less liable to breakage than the ordinary patterns. A small short-necked flask, with bulb about 2½ inches in diameter, should be cleaned and carefully weighed. The neck should be provided with a bored cork (*not* caoutchouc plug), through the hole in which the stem of the Soxhlet's tube passes. The top of the Soxhlet's tube is provided with a bored cork, into which an upright condenser fits. The bulb of the flask is immersed in boiling water, which is kept boiling throughout the

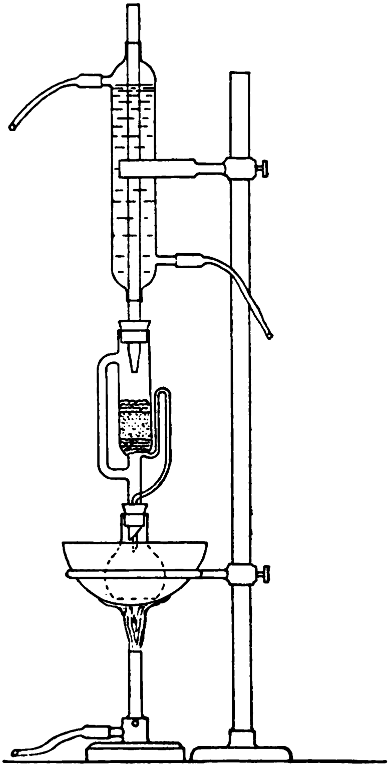

Fig. 61.—Apparatus for determining sulphur in spent oxide.

extraction. A plug of dried cotton wool is placed in the Soxhlet's tube, and on it the dried oxide, above which is pressed another plug of wool. The apparatus is then connected up, and presents the appearance indicated by Fig. 61. A few cubic centimetres of recently distilled and dehydrated carbon disulphide are poured in at the top of the condenser, and pass down through the oxide into the flask. Here the disulphide is quickly evaporated by the heat from the water bath, and the vapour passes up into the condenser, where it is liquefied and drops down and passes again through the oxide. The circulation of the carbon disulphide thus goes on automatically as long as required; the whole of the sulphur will be removed from the oxide in ten to fifteen minutes. The Soxhlet's tube and condenser are then detached from the flask, and the disulphide remaining in the latter is evaporated off, and the flask is placed in a hot-water oven for a quarter of an hour, in order that the last traces of disulphide may be removed. It is then placed in the balance case to cool, and when cool, weighed, the difference between the present weighing and the weight of the empty flask giving the weight of sulphur extracted. The percentage of sulphur in the material is thus found, and the percentage of moisture being known also, the percentage of sulphur on the dried material can be readily calculated. Oxide is not usually considered fully spent until it contains 50 per cent. of sulphur, or about 60 per cent. reckoned on the dry basis. The sulphur which is extracted by the above method may be somewhat contaminated with tarry matter, but if a fairly thick plug of cotton wool is placed beneath the oxide in the tube, and if the gas had been properly treated for the removal of tar before it reached the oxide vessels, the increase in weight caused thereby will be quite negligible.

Where a Soxhlet's apparatus is not available the apparatus described below may be used, and indeed it is preferred in all cases by some operators. The cork fitting the neck of a flask similar to that used with the Soxhlet's tube is bored in two holes, through one of which passes the contracted end of a tube 6 inches in length and ½ an inch in diameter for the upper 5 inches. In this tube the dried oxide is placed, a deep plug of cotton wool being inserted at the shoulder of the tube, and another smaller plug above the oxide. Through the second hole in the cork of the flask passes the end (cut anglewise) of a piece of ¼-inch glass tubing which bends in a horizontal direction above the cork, and at 6 or 8 inches from it, bends downwards and passes through the cork at the top of the worm of a spiral condenser. The outlet tube of the condenser dips beneath water in a beaker. The flask is supported in a bath of boiling water

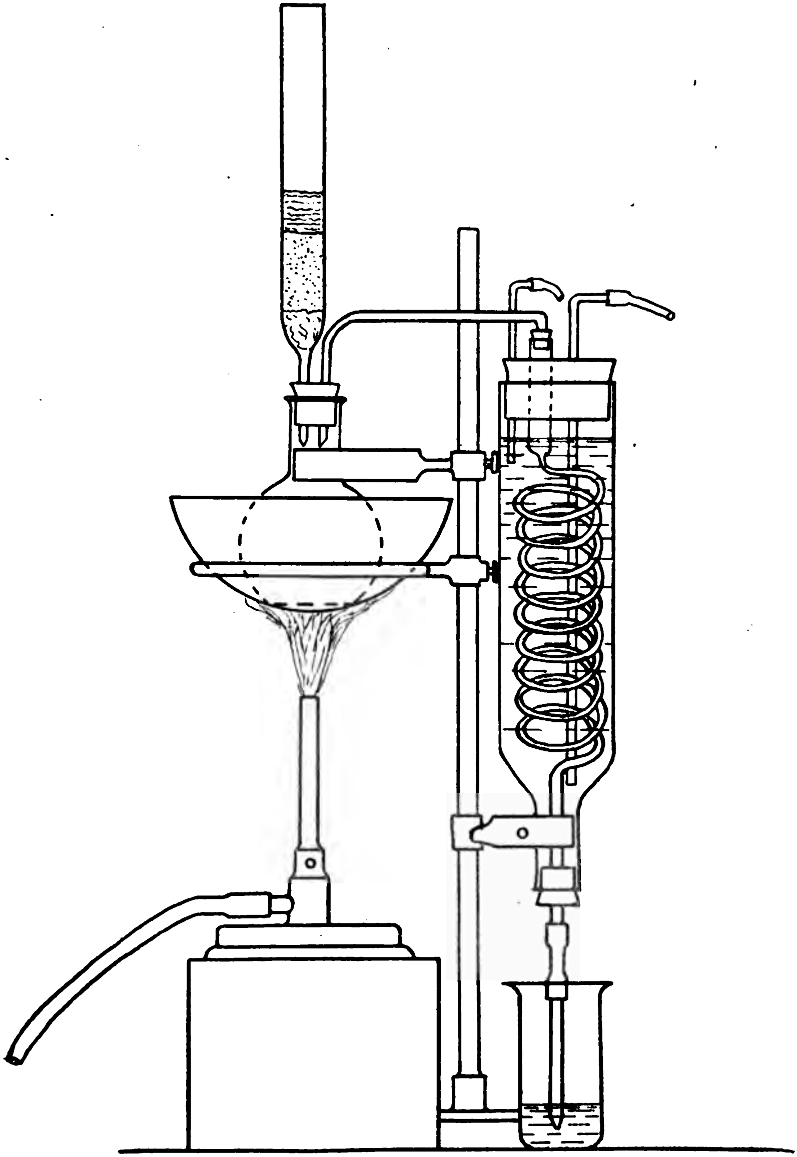

Fig. 62.—Another form of apparatus for determining sulphur in spent oxide.

as in the method described above. The apparatus fitted for use is illustrated in Fig. 62. The tube containing the oxide is filled with carbon disulphide, which passes slowly through the closely packed oxide into the flask, from which it is evaporated by the heat and passes along the horizontal tube, and is condensed in the spiral worm and collected beneath the water in the beaker, the extracted sulphur being deposited in the flask. The tube is refilled with carbon disulphide when the first supply has passed through, and again twice or thrice. If the tube is of the size named, and on each time of filling the disulphide reaches nearly to its brim, four refillings will be ample for the extraction of the whole of the sulphur. When the bulk of the disulphide has evaporated from the flask, the cork may be taken from the latter, and the evaporation of the last traces, and the weighing carried out in exactly the same manner as by the first described method. The disulphide that is condensed and collected in the beaker of course will serve for use again. The washing of the oxide with the carbon disulphide does not appear to be so thorough by this method as when the Soxhlet's apparatus is used, but contrariwise it may be said that the oxide fails to yield any more sulphur if again treated with disulphide after it has been once properly washed in the manner just described.

The total quantity of **ammonia** in spent oxide may be found by digesting 100 grams of the oxide with water for some time, filtering and washing, and estimating the ammonia in the washings and filtrate by distilling with caustic soda in the manner described for ammoniacal liquor. A great part of the ammonia in spent oxide exists as thiocyanate, and it is seldom extracted commercially. The yield on the large scale would be smaller than the above method of estimation would indicate.

Cyanogen compounds exist in spent oxide to a considerable amount when the oxide is used in the first purifying vessel of the series. The approximate yield of **Prussian Blue** from spent oxide may be ascertained as follows:—A weighed portion of the powdered oxide is digested with strong solution of caustic soda, the solution is filtered off and evaporated to dryness with sulphuric acid in excess. The residue is taken up in dilute sulphuric acid, the solution is filtered, and the iron in the filtrate is reduced by zinc or magnesium to the ferrous state and estimated by titration with a standard solution of potassium permanganate. From the amount of iron so found, the amount of ferrocyanide of iron in the spent oxide treated is nearly exactly given by multiplying by 2·2. The residue from the estimation of sulphur should not be used for the cyanide determination, but a fresh portion should be taken. The extraction of cyanide from spent oxide is more practised on the Continent than in this country, the use of oxide in the foremost position in the purifier being more prevalent there. English gas chemists are seldom called upon to make the determination of cyanides in spent oxide. The *Zeitschrift für Analytische Chemie* for 1893 and preceding years contains much information on the methods of estimating ferrocyanide in gas works products.

Spent Weldon Mud.—The **sulphur** in this material is ordinarily estimated by precisely similar methods to those given for the sulphur in spent oxide of iron. The result represents the free sulphur present in the Weldon mud. But a certain amount of sulphur present in a combined state is also extracted from the spent Weldon mud by the method now adopted for its regeneration. This extra quantity amounts to 1·5 per cent. and upwards on the mud. The total available sulphur in Weldon mud may be estimated as follows :—100 grains of the spent mud is dissolved in dilute hydrochloric acid, filtered, and the residue on the filter well washed and thoroughly dried in a hot-water oven. The filter paper, with its contents, is transferred to the extraction apparatus, and the sulphur is extracted with carbon disulphide in the usual manner. A separate portion of the mud is taken for the determination of moisture. Sulphur in Weldon mud is generally recovered as such, and hence is far more valuable than sulphur in spent oxide of iron, which is burnt for the production of sulphuric acid, and hence has virtually only the value of pyritic sulphur.

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